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**FINAL
COMPREHENSIVE TECHNICAL REPORT
FOR THE EVALUATION OF THERMATRIX GS
SERIES FLAMELESS THERMAL OXIDIZER FOR
OFF-GAS TREATMENT OF SOIL VAPORS
CONTAINING VOLATILE ORGANIC COMPOUNDS**



NOVEMBER 1998

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE (AFCEE)
TECHNOLOGY TRANSFER DIVISION**

FINAL

**COMPREHENSIVE TECHNICAL REPORT FOR
THE EVALUATION OF THERMATRIX GS SERIES FLAMELESS
THERMAL OXIDIZER FOR OFF-GAS TREATMENT OF SOIL
VAPORS CONTAINING VOLATILE ORGANIC COMPOUNDS**

**Prepared for
AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE, TEXAS**

**Prepared by
Parsons Engineering Science, Inc.
Denver, Colorado**

November 1998

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PREFACE

Parsons Engineering Science, Inc. (Parsons ES) was contracted by the Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division (ERT) to perform a demonstration of flameless thermal oxidation technology at three demonstration sites throughout the United States, including:

- Site FT-002, Plattsburgh Air Force Base (AFB), New York;
- Building 181, Air Force Plant 4, Fort Worth, Texas; and
- Source Area Reduction System, former Lowry AFB, Colorado.

The work was performed for AFCEE/ERT under Contract F41624-94-D-8136, Delivery Order 28.

Key AFCEE/ERT personnel:

Mr. James R. Gonzales - Project Manager

Key Plattsburgh AFB personnel:

Brady Baker - AFBCA (formerly at Plattsburgh AFB, now at F.E. Warren AFB)

Joe Szot - AFCEE/OL3A

Key Air Force Plant 4 personnel:

John Doepker - ASC/EMVR

Luke Gilpin - Lockheed Martin

Terry Murphy, Texas Natural Resource Conservation Commission

Key Former Lowry AFB personnel:

Bruce Kroehl - AFBCA DB

John Miller - AFCEE/ERB

Barbara O'Grady, Colorado Department of Public Health and Environment (CDPHE)

Floyd Nichols, US Environmental Protection Agency, Region 8

Chip Hancock, CDPHE Air Pollution Control Division

Key Parsons ES personnel:

Steven R. Archabal - Site Manager

Douglas C. Downey - Technical Director

Peter R. Guest - Project Manager

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- B - FTO System Sampling and Monitoring Information
- C - Site Analytical Data Tables
- D - Vapor Treatment Technology Cost Comparison

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LIST OF ACRONYMS AND ABBREVIATIONS

°F	Degrees Fahrenheit
1,1-DCE	1,1-Dichloroethene
AFB	Air Force Base
AFBCA	Air Force Base Conversion Agency
AFCEE	Air Force Center for Environmental Excellence
AFP	Air Force Plant
APCD	Air Pollution Control Division
APEN	Air Pollution Emission Notice
bgs	Below ground surface
CAHs	Chlorinated aliphatic hydrocarbons
CDPHE	Colorado Department of Public Health and Environment
cfm	Cubic feet per minute
cis-1,2-DCE	cis-1,2,-Dichloroethene
CO	Carbon monoxide
CTR	Comprehensive Technical Report
DoD	Department of Defense
DPE	Dual-phase-extraction
DRE	Destruction/removal efficiency
ESE	Environmental Science and Engineering, Inc.
FTO	Flameless thermal oxidation
GAC	Granular activated carbon
HCl	Hydrochloric acid
IRP	Installation Restoration Program
lb/hr	Pounds per hour
lb/yr	Pounds per year
NOx	Nitrogen oxide
NYSDEC	New York Department of Environmental
Parsons ES	Parsons Engineering Science, Inc.
PCE	Tetrachloroethene
ppmv	parts per million, by volume
SARS	Source Area Reduction System
SVE	Soil vapor extraction
SVEPP	SVE pilot plant
TCE	Trichloroethene
TNRCC	Texas Natural Resource
TOV	Total organic vapors
US	United States
VE	Vapor extraction
VE/VWs	Vapor extraction/vent wells
VFD	Variable frequency drive
VOCs	Volatile organic compounds

SECTION 1

INTRODUCTION

This document was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence (AFCEE) as part of a demonstration of the flameless thermal oxidation (FTO) vapor-phase treatment technology for soil vapor extraction (SVE) off-gas abatement at three demonstration sites throughout the United States (US). The demonstration sites included (Figure 1.1):

- Former Fire Training Area (Site FT-002), at Plattsburgh Air Force Base (AFB), New York;
- Building 181 at Air Force Plant (AFP) 4, Fort Worth, Texas; and
- Source Area Reduction System (SARS), at the former Lowry AFB, Colorado.

This Comprehensive Technical Report (CTR) summarizes the results of the three demonstrations, which have been previously presented in the following reports:

- *Final Site-Specific Technical Report for the Evaluation of Thermatrix GS Series Flameless Thermal Oxidizer for Off-Gas Treatment of Soil Vapors with Volatile Organic Compounds at Site FT-002, Plattsburgh Air Force Base, New York* (Parsons ES, 1997);
- *Final Site-Specific Technical Report for the Evaluation of Thermatrix GS Series Flameless Thermal Oxidizer for Off-Gas Treatment of Trichloroethene Vapors at Building 181, Air Force Plant 4, Texas* (Parsons ES, 1998b); and
- *Final Site-Specific Technical Report for the Evaluation of Thermatrix GS Series Flameless Thermal Oxidizer for Off-Gas Treatment of Soil Vapors with Volatile Organic Compounds at the Source Area Reduction System, Former Lowry Air Force Base, Colorado* (Parsons ES, 1998c).

Upon completion of the FTO demonstration at the former Lowry AFB, the FTO unit was transferred to McClellan AFB, California. The effective date of the transfer, September 17, 1998, was the date the system was delivered to McClellan AFB. A summary of site demonstration durations and final disposition of the FTO unit is provided in Table 1.1.

1.1 SCOPE AND OBJECTIVES OF DEMONSTRATION

Under contract to AFCEE, Parsons ES collected cost and performance data to determine the applicability of using FTO technology for treatment of extracted soil

Former Lowry AFB, Colorado

Plattsburgh AFB, New York

Air Force Plant 4, Texas

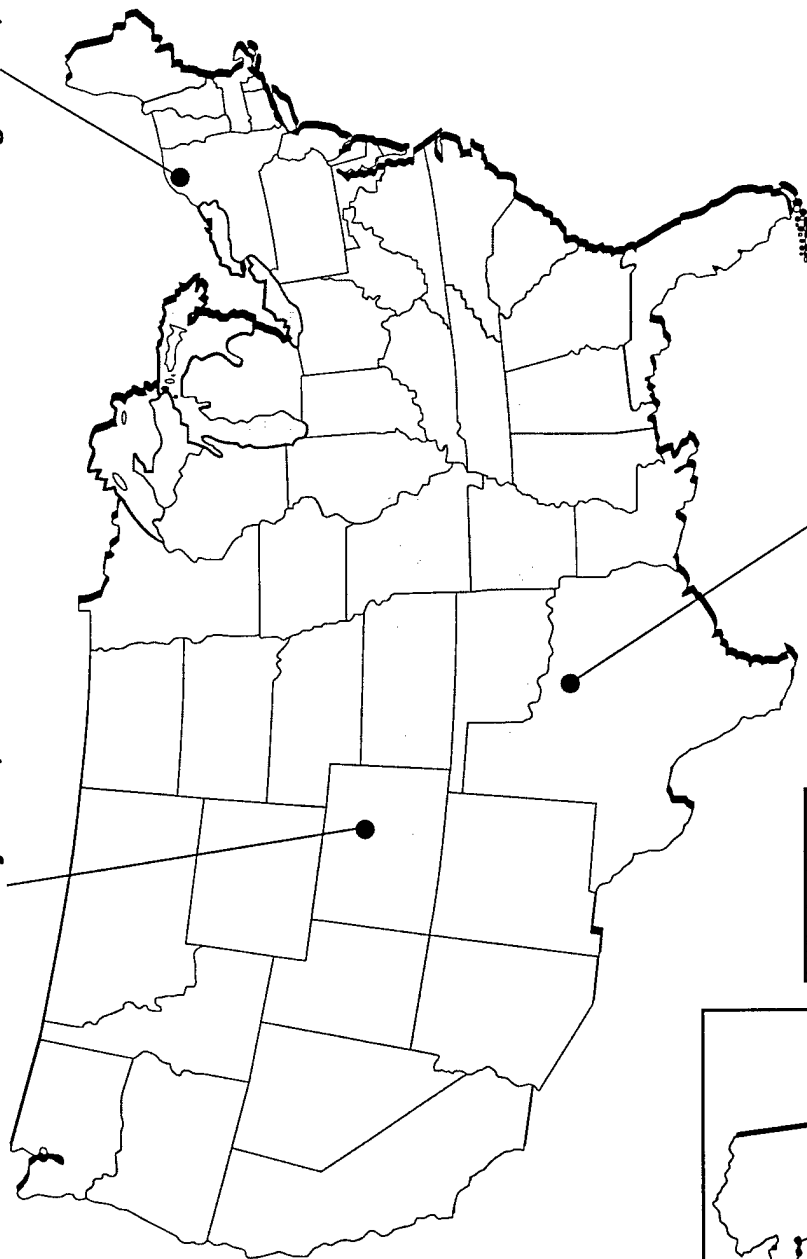


FIGURE 1.1

DEMONSTRATION SITE LOCATIONS

FTO Treatment System Demonstration
Comprehensive Technical Report

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

TABLE 1.1
SITE DEMONSTRATION DURATIONS AND FTO UNIT DISPOSITION
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Location	Demonstration Site	Operating/Reporting Period	Demobilization Date
Air Force Plant 4	Building 181	March 16, 1996-April 30, 1996 ^{a/}	April 30, 1996
Plattsburgh AFB	Former Fire Training Area (Site FT-002)	August 27, 1996 – March 25, 1997	March 27, 1997
Air Force Plant 4	Building 181	April 25, 1997 - October 15, 1997	March 11, 1998
Former Lowry AFB	Source Area Reduction System (SARS)	May 20, 1998 – September 1, 1998	September 15, 1998 ^{b/}

^{a/} A series of equipment malfunctions and programmable logic controller errors precluded successful demonstration of the FTO system during this period of time, and site-specific data were not collected. Following repairs made by Thermatrix, the FTO system was mobilized to Plattsburgh AFB in August 1996.

^{b/} The FTO system was transferred to McClellan AFB, CA. The effective date of the transfer, September 17, 1998, was the date of delivery of the system to McClellan AFB.

vapors containing chlorinated and non-chlorinated volatile organic compounds (VOCs) at three Air Force sites. This CTR summarizes the results of the demonstrations by presenting:

- Analytical data collected during the demonstrations;
- FTO cost and performance data collected during the demonstrations;
- An analysis of the FTO vapor treatment efficiency and cost comparison to other technologies;
- An assessment of the applicability of this technology based on vapor treatment efficiency and cost; and
- An overview of lessons learned and recommendations resulting from this demonstration.

1.2 REPORT ORGANIZATION

This CTR is divided into six sections and three appendices. A summary of the report contents follows:

- **Section 1:** Introduction and brief summary of this CTR;
- **Section 2:** A description of the FTO vapor-phase treatment technology;
- **Section 3:** A detailed summary of the field demonstration results;
- **Section 4:** Conclusions regarding the overall performance of the FTO technology;
- **Section 5:** Recommendations regarding the use of FTO technology at Department of Defense (DoD) installations;
- **Section 6:** Listing of the references cited in this document;
- **Appendix A:** Vendor information;
- **Appendix B:** FTO system sampling and monitoring information;
- **Appendix C:** Site analytical data tables; and
- **Appendix D:** Vapor treatment technology cost comparison.

SECTION 2

DESCRIPTION OF TECHNOLOGY

2.1 DESCRIPTION OF THERMATRIX GS SERIES FLAMELESS THERMAL OXIDATION SYSTEM

FTO is a technology that can be used to treat extracted soil vapors that contain chlorinated and/or petroleum hydrocarbons. The extracted vapors are heated to temperatures sufficient to oxidize chemical constituents and form carbon dioxide and water vapor, and, in the case of chlorinated hydrocarbons, hydrochloric acid (HCl).

Thermatrix, Inc. of Knoxville, Tennessee has developed a proprietary technology for FTO of VOCs in vapor streams. The Thermatrix GS Series FTO system employs a single-pass corrosion resistant, packed-bed ceramic matrix. The ceramic matrix is immune to moisture and acid, noncatalytic, and have a temperature rating of up to 2,500 degrees Fahrenheit (°F). The oxidizer materials (i.e., thermal wells) have a temperature rating of up to 2,200°F, and may be susceptible to corrosion following prolonged exposure to acidic vapor. The oxidation of VOCs in the influent vapor stream occurs in a reaction zone established within the ceramic matrix, where typical operating temperatures range from 1,600 to 1,850 °F. System exhaust gases can be discharged directly into the atmosphere, or routed through a caustic scrubber to remove HCl, if the influent vapors contain chlorinated VOCs. Thermatrix FTO system information is provided in Appendix A.

The FTO system for the AFCEE demonstration project was a GSC-120M model designed to extract and treat chlorinated and non-chlorinated hydrocarbon vapors at influent flow rates between 20 and 120 cubic feet per minute (cfm), and to reduce the influent VOC concentrations by not less than 99.99 percent. Extracted soil vapors are directed (under pressure) at a regulated flow rate into the FTO unit via the FTO blower system, which consists of a regenerative vacuum pump. Vapors initially pass through the static premixing chamber (where thorough mixing of soil vapor and supplemental fuel [propane] occurs), and then flow into the reaction bed where complete oxidation occurs at a temperature of approximately 1,800°F.

When the influent vapor stream reaches oxidation temperature, organic compounds react within the oxidizer vessel to form carbon dioxide, water, and (in the case of chlorinated hydrocarbons) HCl, releasing heat that is then absorbed by the ceramic matrix of the reaction bed. The GS Series FTO unit allows for a single pass of the extracted vapors through the oxidizer at a space velocity of 7,200 hours⁻¹ (nominal residence time of 0.5 second). A schematic of the FTO treatment process is presented on Figure 2.1. The system tested at the three sites included an effluent caustic scrubber

**Flameless Thermal Oxidizer
("Straight Through Style")**

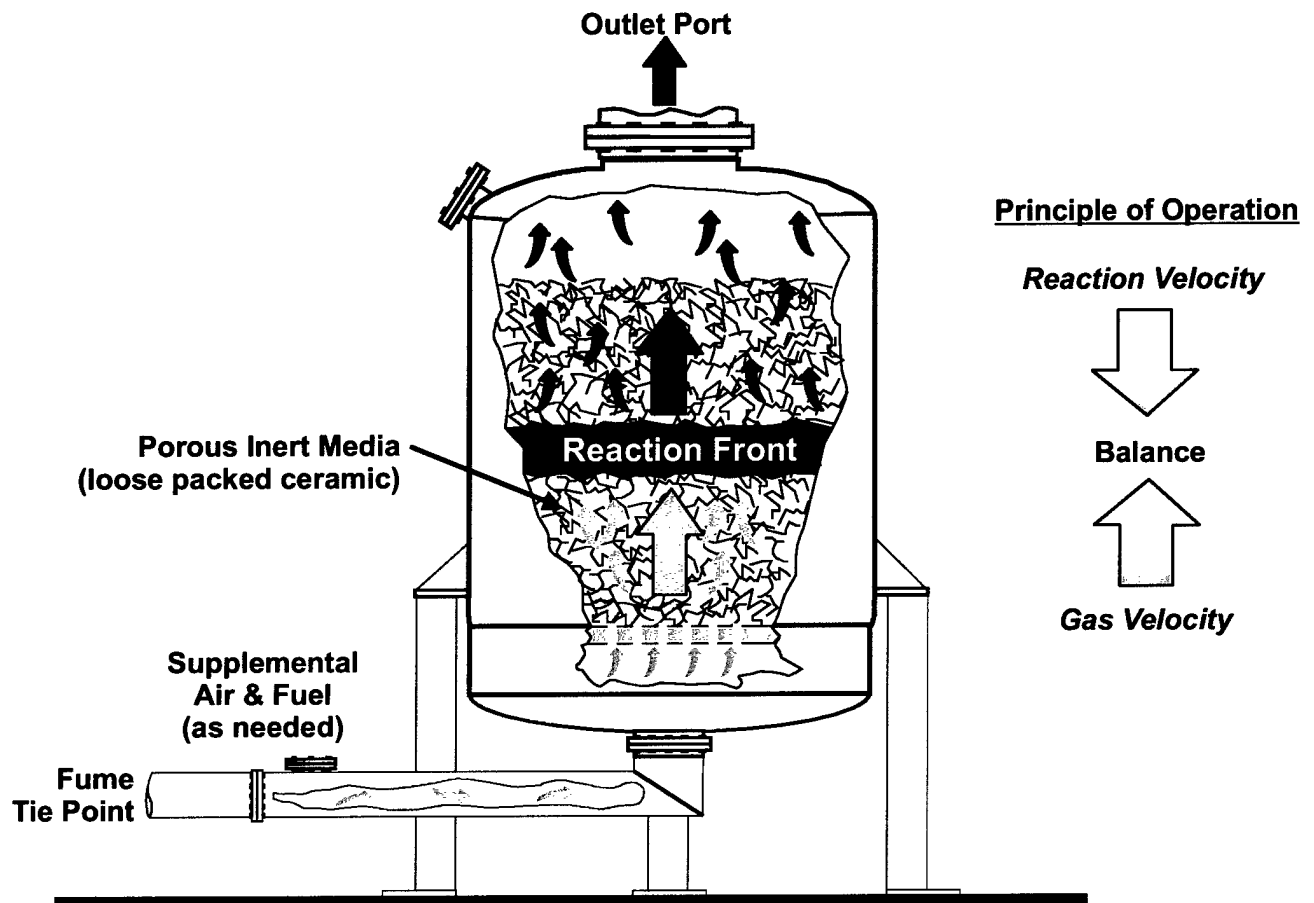


FIGURE 2.1

**SCHEMATIC OF FTO
TREATMENT PROCESS**

FTO Treatment System Demonstration
Comprehensive Technical Report

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

that was designed to remove at least 99.5 percent of HCl from the reactor exhaust at the maximum design loading rate of approximately 3 pounds per hour (lb/hr) of HCl. When the scrubber is used to achieve maximum HCl removal from the reactor exhaust, the influent VOC loading rate that the FTO unit can treat may decrease. Air emissions limits for HCl required the use of the scrubber at AFP 4, but the scrubber was not needed during the demonstrations conducted at Plattsburgh AFB and the former Lowry AFB. A complete process flow schematic of the FTO system is shown in the P&IDs presented in Appendix A.

The FTO system is skid-mounted on a trailer with a dedicated electrical distribution system. The system is designed to operate within single-circuit, 480-volt, 3-phase, 60-amp electrical power limitations. The system is partially enclosed for protection of system components that could be affected by temperature, moisture, and/or windblown particulates.

Based on information provided by Thermatrix, a series of tests have demonstrated the inherent safety of the FTO system (Meltzer, 1992). Conditions considered to be worst-case from a safety standpoint were investigated by Thermatrix. Flow rates and concentrations of VOCs (as propane) were varied over wide ranges. The different flow rates tested through the unit resulted in residence times ranging from 0.15 second to 10 minutes, and VOC concentrations between 1,000 and 160,000 parts per million, volume per volume (ppmv), spanning the flammability range of 5 percent of the lower explosive limit to 170 percent of the upper explosive limit. Under all test conditions, no flashback or detonation occurred (Meltzer, 1992).

In many flame-based thermal oxidizers, some of the soil vapor can bypass the flame zone, potentially resulting in the formation of products of incomplete combustion. The configuration of the flameless oxidizer is designed to eliminate these problems. The reaction zone covers the entire cross-section of the ceramic matrix (Figure 2.1), resulting in all vapor passing through the reaction zone before it exhausts from the oxidizer as carbon dioxide, water, and HCl.

Complete conversion of the VOCs into harmless byproducts and HCl occurs rapidly in the reaction zone of the FTO unit because of thorough premixing of the contaminated influent vapors with air (oxygen) and supplemental fuel (propane), and the heat-transfer properties of the ceramic matrix. Testing by Thermatrix has shown that even a minimal residence time of as little as 0.15 second in the FTO can result in greater than 99.99-percent destruction/removal efficiency (DRE) for hydrocarbon vapors. The flameless oxidizer tested in this demonstration project has a nominal residence time of 0.5 second (Thermatrix, 1992).

According to Thermatrix (1992), the FTO technology is capable of processing batch- or variable-flow vapor streams because of the heat-retention and radiant-heat properties of the ceramic matrix. The technology can handle VOC vapor spikes above nominal capacity, or a complete interruption in contaminant vapor flow, and remain functionally on-line with no disruption of DRE or safety concerns (as could occur in a flame-based unit resulting in a flame blow out).

Although influent vapors can vary in hydrocarbon concentration, a minimum 12-percent oxygen in the influent vapor is required to sustain an efficient oxidation process. Because many hydrocarbon-contaminated sites have low initial soil gas oxygen levels, soil gas dilution with ambient air is often required to ensure that sufficient oxygen enters the oxidizer.

Performance tests by Thermatrix have demonstrated a 99.99-percent and greater DRE of the FTO system for a wide variety of VOCs, including chlorinated hydrocarbons (Meltzer, 1992; Thermatrix, 1992). Tests also have measured typical nitrogen oxide (NOx) emissions of less than 2 ppmv, and carbon monoxide (CO) emissions of less than 10 ppmv. Single-component and mixed organic vapor streams have been successfully treated, with vapor constituents that have included benzene, carbon tetrachloride, dichloromethane, ethyl chloride, isopropanol, methane, paint solvent mixtures, propane, and toluene. These compounds are chemically representative of many of the types of industrial VOCs, including chlorinated aliphatic hydrocarbons, that can be treated with FTO technology. The test procedures, analytical methods, and performance results for the GS Series FTO unit are detailed in a separate vendor report (Thermatrix, 1992).

2.2 CAPITAL EQUIPMENT COSTS

Table 2.1 provides the capital costs for the Thermatrix GS Series FTO treatment system purchased for this demonstration program. The FTO treatment system was purchased by the Air Force from Thermatrix on a "shared-cost" basis. The Thermatrix contribution was \$40,000, which was the difference between the equipment funding provided by the Air Force and the established commercial value of the FTO system. Therefore, the cost to the Air Force for the FTO system was \$235,265, versus an actual commercial value of \$275,265.

Thermatrix manufactures FTO systems that have influent vapor flow capacities ranging from 1 to 30,000 cfm. During this demonstration project, FTO technology was compared to other vapor-phase treatment technologies and price quotes were obtained from Thermatrix for FTO treatment systems with capacities of 80 cfm, 250 cfm, 500 cfm, 850 cfm, and 1,140 cfm (see Table 2.2).

2.3 REGULATORY ACCEPTANCE

Acceptance of Thermatrix FTO systems by regulatory agencies has been widespread. Agencies that have approved this technology for site remediation include state environmental agencies, and local air quality districts. The states and countries that have permitted (or exempted) Thermatrix FTO systems to date are listed in Table 2.3.

For long-term testing (more than a 1- to 5-day pilot test), regulatory approval is generally required. Approval for long-term extracted soil vapor treatment is site-specific (geographically). In some areas, only a work plan or letter notification may be necessary. In other areas, submittal of an air emissions permit application also may be required. For shorter-term, 1- to 5-day pilot test, permits usually are not required. Local regulatory officials should be contacted to verify local requirements.

TABLE 2.1
SUMMARY OF CAPITAL COSTS FOR THERMATRIX GSC-120M FTO UNIT
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Item	Cost
Thermatrix Engineering and Project Management	\$16,000
Basic FTO Treatment Unit	\$164,000 ^{a/}
Quench/Scrubber System	\$62,000 ^{b/}
FTO System Trailer	\$19,500 ^{c/}
SVE Blower and Knockout Drum	\$3,615
Electrical Equipment	\$4,900
Control Valves	\$4,500
Miscellaneous Items	<u>\$750</u>
TOTAL	\$275,265

^{a/} This cost includes \$40,000 contributed by Thermatrix for the design and fabrication of the FTO system.

^{b/} Required for chlorinated hydrocarbons.

^{c/} Optional; required for mobile unit only.

TABLE 2.2
CAPITAL COST FOR THERMATRIX FTO TREATMENT SYSTEMS^{a/}
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

FTO Treatment System Model ^{b/} (Capacity in cfm ^{c/})	ES100 (100)	GS250 (250)	GS500 (500)	GR500 (500)	GS850 (850)	GS1200 (1200)
Capital Cost (\$)	95,000 ^{d/}	195,000 ^{e/}	250,000 ^{f/}	250,000 ^{f/}	373,400 ^{g/}	403,400 ^{h/}

^{a/} Thermatrix is an engineered-solution provider that custom manufactures equipment based on site-specific requirements. Therefore, prices may vary depending on customer requirements.

^{b/} ES = Electrical straight-through; GS = Gas straight-through; GR = Gas recuperative.

^{c/} cfm = cubic feet per minute

^{d/} Source: Based on quote received September 14, 1998 by Parsons ES from Thermatrix, Inc. (Susan T. DesJardin).

^{e/} Source: Based on verbal quote received October 1, 1998 by Parsons ES from Thermatrix, Inc. (Richard Scheig). FTO treatment system includes soil vapor extraction equipment and quench/scrubber.

^{f/} Source: Based on verbal quote received October 1, 1998 by Parsons ES from Thermatrix, Inc. (Richard Scheig).

^{g/} Source: Based on quote received December 19, 1997 by Parsons ES from Thermatrix, Inc. (Richard Scheig). FTO treatment system includes quench/scrubber.

^{h/} Source: Based on quote received December 19, 1997 by Parsons ES from Thermatrix, Inc. (Richard Scheig). FTO treatment system includes quench/scrubber.

TABLE 2.3
REGULATORY ACCEPTANCE OF FTO TECHNOLOGY
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

United States	
California	Connecticut
Idaho	Indiana
Kentucky	Louisiana
Maryland	Massachusetts
Michigan	Minnesota
Mississippi	Montana
New Jersey	New York
North Carolina	Ohio
Pennsylvania	South Carolina
Tennessee	Texas
Utah	
Outside of United States	
Canada	England
France	Ireland
Japan	Netherlands
Switzerland (pending)	Taiwan, R.O.C. have approved the use of this system.

[Source: Thermatrix.]

SECTION 3

FIELD DEMONSTRATION RESULTS

3.1 SITE BACKGROUND AND REGULATORY REQUIREMENTS

The following sections provide a brief overview of each demonstration site's history and background. More detail regarding each site can be found in the individual site-specific technical reports referenced in Section 1 of this report.

3.1.1 Plattsburgh AFB, New York

Site FT-002 is a former fire protection training area that was used from the mid- to late 1950s through 1989, when it was closed to dedicated fire training activities. Training activities involved the release of waste fuels and solvents into unlined earthen pits, where the fuels were ignited and extinguished. Uncombusted fuels and solvents percolated into the soils, resulting in contamination of soils and groundwater.

Several site investigations have been conducted at Site FT-002, under the Air Force Installation Restoration Program (IRP), to characterize soil and groundwater contamination. Detailed descriptions of the nature and extent of site contaminants are provided in the FTO system demonstration work plan (Parson ES, 1996a). The results of previous investigations indicate that soil and groundwater at and downgradient from the FT-002 fire training area are impacted with JP-4 jet fuel compounds and chlorinated solvents. The depth to groundwater at the site averages approximately 35 feet below ground surface (bgs).

To treat the contaminated soil at Site FT-002, a full-scale SVE system was designed by OHM, the primary remedial action contractor for Plattsburgh AFB. The full-scale system was installed during 1996 and 1997, and included 14 vapor extraction/vent wells (VE/VWs), a vacuum blower and ancillary equipment, and a vapor-phase treatment system.

Testing of the FTO system was conducted over a 30-week period from August 27, 1996 to March 25, 1997. The VE/VWs and SVE system provided the source hydrocarbon vapors for testing the FTO system. Individual wells and/or pairs of wells were tested for periods of up to 2 weeks per well (or well pair) to determine the optimum vacuum/extraction flow rate balance among all wells and the soil vapor VOC concentration for each well.

As part of the technology demonstration at Site FT-002, an application for a permit to construct/certificate to operate a process, exhaust, or ventilation system was submitted to the New York State Department of Environmental Control (NYSDEC)

(Parsons ES, 1996b). Approval for the FTO demonstration was given by NYSDEC (1996) prior to startup.

3.1.2 Air Force Plant 4, Texas

Building 181 is located in the southwestern corner of the assembly/parts plant at AFP 4. Historically, parts degreasing operations were performed in the northwestern corner of Building 181.

In May 1991, plant personnel noted that an excessive amount of solvent (TCE) was required to fill one of the 1,500-gallon degreasing tanks (tank 544). Shortly thereafter, the tank was discovered to be leaking. Additionally, several surface spills had been reported within Building 181, although the exact volumes and locations of the spills were not documented in the available review material (Environmental Science & Engineering, Inc. [ESE], 1994a). On July 15, 1991, degreasing TCE storage tanks 34 and 544 were removed from service (Hargis & Associated, Inc. [Hargis], 1992).

Based on the Hargis (1992) site investigations, the highest contaminant concentrations in the subsurface were detected near the former degreasing tanks in Building 181. The depth to perched groundwater beneath the site ranges from 1 to 5 feet bgs, and the unconfined aquifer occurs approximately 23 feet bgs. A more detailed description of the nature and extent of site contaminants is provided in the FTO system demonstration work plan (Parsons ES, 1996a).

In November 1993, an SVE pilot plant (SVEPP) was installed by ESE (1994b) to conduct a 3-month treatability test to determine the soil air permeability near each of eight SVE wells, the radius of influence around each extraction well, and the concentrations of VOCs in the extracted soil gas. Based on the results of analysis of soil gas samples collected after the 90-day SVEPP test, significant TCE concentrations remained at several of the extraction wells and monitoring point locations. During the SVEPP test, the extracted soil vapor was treated using granular activated carbon (GAC) prior to being discharged to the atmosphere. Because the loading capacity of GAC is relatively low when treating TCE (typically 10 percent at 90-percent relative humidity), operating a GAC system at this site is expensive. A more cost-effective vapor treatment technology for the Building 181 site was desired. Jacobs Engineering (1997) performed a technical analysis on the existing SVEPP system, and is completing the design of a full-scale SVE system that is anticipated to be installed by the end of 1998.

The FTO system was connected to eight existing vapor extraction (VE) wells (UZ-1 and PZ-1 through PZ-7), a potable water source, and associated vapor line manifold piping installed by ESE in 1993 for the SVEPP. Tie-ins of the FTO system to the existing SVEPP piping system were made downstream from the manifold portion of the vapor line piping and upstream from the existing blower in order to maintain independent control of vapor flow from each well during the demonstration period. The existing GAC vapor treatment component of the SVEPP system associated with Building 181 was not operated during the FTO demonstration period; only the SVEPP groundwater treatment system was operated concurrently with the Thermatrix FTO unit. Additional information on the SVEPP system is documented in *Soil Vapor Extraction Pilot Plant Study, Building 181, Fort Worth, Texas* (ESE, 1994b).

To ensure compliance with the Texas Clean Air Act as implemented by the Texas Natural Resource Conservation Commission (TNRCC), Parsons ES, in conjunction with AFP 4 and AFCEE, prepared the necessary documentation to obtain approval to conduct the pilot-scale demonstration of the FTO system at Building 181, AFP 4 (Parsons ES, 1996a). The maximum TCE loading rate calculated for the FTO system during the demonstration was 3.67 lbs/hr, based on the maximum allowable emission rate for HCl of 0.01 lb/hr.

3.1.3 Former Lowry AFB, Colorado

The "source area" at which the SARS is located refers to the area at the former Lowry AFB beneath the Westerly Creek storm sewer outfall pipes. The source area was identified in previous IRP investigations as an upgradient source of TCE contamination currently impacting groundwater in the north-central and north-northwestern portions of the former Base. Industrial wastes, such as greases and solvents associated with aircraft maintenance, may have been discharged into the storm sewer system (Parsons ES, 1995). More recent investigations, including the *Draft Preliminary Site Characterization Summary Report Operable Unit 5, Groundwater* (Versar, Inc., 1995), summarized the nature and extent of the TCE contamination at the former Lowry AFB.

Several site investigations have been conducted under the Air Force IRP to characterize soil and groundwater contamination and to collect data to evaluate remedial technologies at the TCE impacted source area. In March and April 1995, an interim remedial action field investigation was conducted by Versar and Remediation Technologies, Inc. (1996) to provide additional information on the nature and extent of the contamination in the soil and groundwater, and to provide a basis for screening remedial technologies in a detailed analysis of alternatives. The field investigation consisted of drilling 15 soil borings, and installing 6 monitoring wells and 23 piezometers. A dual-phase-extraction (DPE) pilot test and an aquifer pump test were also conducted during the investigation. Based on the results of these investigations, the remedial action selected as the most appropriate technology for the SARS included a combination of slurry-wall isolation and DPE wells for *ex situ* treatment of extracted groundwater and soil vapors.

The purpose of the SARS is to reduce a significant portion of the mass of TCE and other VOCs within the source area. Source-mass reduction is being accomplished by lowering the groundwater table in the treatment area, and currently extracting VOC-contaminated soil vapors using a system of DPE wells. A slurry wall has been installed around the DPE wells to isolate the source area and reduce the inflow (recharge) of groundwater into the treatment area (Versar, Inc. and Remediation Technologies, Inc., 1996).

The SARS was constructed for the Air Force by Versar. The SARS consists of 15 DPE wells, a liquid-ring vacuum pump, two water transfer pumps, an air/water separator tank, three carbon canisters, and associated piping and instrumentation. During the FTO technology demonstration at the former Lowry AFB, the FTO system was used to treat a portion of the vapors (slip-stream) that were being extracted via the DPE wells installed by Versar.

To ensure compliance with the Colorado State Air Emissions Guidelines as implemented by the Colorado Department of Public Health and Environment (CDPHE) Air Pollution Control Division (APCD), Parsons ES coordinated with Versar and CDPHE APCD to ensure that relevant air emissions permitting requirements for the FTO system were met. Parsons ES, as directed by the Lowry Air Force Base Conversion Agency (AFBCA), submitted the required Application for Construction Permit and Air Pollution Emission Notice (APEN) for review and approval by CDPHE APCD (Parsons ES, 1998a). Approval of the APEN by CDPHE APCD allowed up to 2,060 pounds per year (lb/yr) of uncontrolled hazardous air pollutants (i.e., HCl) during the operation of the FTO system.

3.2 DEMONSTRATION PROTOCOL AND CONDITIONS

3.2.1 Demonstration Protocol

The demonstration protocol for each site included performance of some or all of the eight following tasks:

- Each demonstration began with a site meeting and a technology briefing for Base officials. This provided a time for questions to be raised regarding the operating of the system, regulatory requirements, and ultimate objectives of the demonstration at the individual sites.
- A site-specific work plan was prepared describing where and how the test would be conducted. The work plan provided a brief overview of the site history and characteristics and detail on FTO system start-up, extended operation, monitoring and maintenance.
- Existing VWs and monitoring points installed previously at the sites in support of other remediation efforts, were selected for use in the demonstrations.
- With the exception of the former Lowry AFB, a baseline soil gas survey was conducted to aid in assessing the overall effectiveness of vapor extraction at the site during the demonstration period. Hand-held instruments were used in the field to obtain measurements for oxygen (GasTech®), carbon dioxide (GasTech®), and total organic vapors (TOV) (Photovac MicroTIP™) in soil gas.
- Start-up procedures consisted of a 5- to 10-day optimization test to ensure that the FTO unit was operating properly (see Appendix B for FTO treatment system sampling and monitoring schedule):
 - ⇒ During the initial testing, air flow rates, vacuum, makeup water consumption (if quench/scrubber was used), supplemental fuel usage, and oxidizer temperature were adjusted to optimize vapor extraction rates and treatment efficiency.
 - ⇒ Field (TOV) and laboratory (VOC analysis using US Environmental Protection Agency [USEPA] Method TO-14) samples of the influent and effluent vapor streams were collected to ensure proper operation of the FTO unit. Appendix B presents the list of target VOCs reported by Air Toxics LTD. of Folsom, California using USEPA TO-14.

- After the start-up period and optimization of the FTO system, an extended operation and performance evaluation began (see Appendix B for FTO treatment system sampling and monitoring schedule):
 - ⇒ In general, extended system operation consisted of daily confirmation of operation by base personnel and bi-weekly (twice per month) site visits by Parsons ES technicians to perform vapor sampling and routine maintenance.
 - ⇒ Bi-weekly sampling events consisted of collecting influent and effluent vapor samples for laboratory VOC analysis using USEPA Method TO-14. In addition, analysis for HCl in emissions using National Institute of Occupational Safety and Health Method 7903 was conducted at AFP 4 to evaluate the effectiveness of the quench/scrubber system. Periodically (10-percent of the total samples collected), quality assurance/quality control samples in the form of field duplicates were collected to assess the laboratory performance. With the exception of samples collected between September 1996 and February 1997 at Plattsburgh AFB, influent and effluent samples were collected following the sampling procedures described in the letter dated March 13, 1997 (see Appendix B).
 - ⇒ System operational parameters monitored on a biweekly basis included system flow-rates (flow rate into oxidizer, extracted vapor portion of flow rate, and ambient air portion of flow rate), vacuum, makeup water consumption and pH of water discharge (if quench/scrubber was used), run time, thermocouple temperatures in the oxidizer, and supplemental fuel usage.
 - ⇒ Routine maintenance of the FTO system consisted of:
 - Checking and filling oil reservoir on the water pump (if quench/scrubber was used);
 - Emptying the condensate knockout drum;
 - Cleaning water filter/strainer (if quench/scrubber was used);
 - Checking/replacing the blower inlet pre-filter, as necessary;
 - Checking caustic chemical usage and supply (if quench/scrubber was used);
 - Checking the supplemental fuel usage and supply; and
 - Adjusting water flow rates, as necessary (if quench/scrubber was used).
- After completing the demonstration at a site, the FTO unit was demobilized from the site and moved to the next site. At the completion of the demonstration at the former Lowry AFB, the FTO unit was transferred to McClellan AFB (see Table 1.1).

3.2.2 FTO Configuration

The FTO configuration at each site is summarized below:

- Vapors were extracted from a single or multiple VE/VWs at Plattsburgh AFB; from multiple VE wells at Air Force Plant 4; and at the former Lowry AFB, soil gas extracted by the SARS was diverted to, and treated by the FTO unit during the demonstration.
- Vapors were transmitted to the trailer-mounted FTO unit via manifolded polyvinyl chloride piping originating at the VE/VWs at Plattsburgh AFB, and from the SVEPP and SARS at AFP 4 and the former Lowry AFB, respectively.
- Prior to entering the FTO unit, the vapor stream passed through a pre-filter and knockout drum to remove particulates and condensate, respectively.
- The vapors then passed through the static premixing chamber (combining extracted vapors with supplemental fuel and ambient air), and then into the reaction bed where complete oxidation occurred at approximately 1,800°F. Supplemental fuel in the form of propane (from a 500-gallon storage tank) was supplied to the FTO unit as necessary in order to sustain the proper reactor bed temperature.
- Following treatment, the vapor stream passed through the exhaust system to the atmosphere or through the quench/scrubber system (AFP 4 only).
- Various vapor sampling ports on the FTO unit allowed sampling of the influent vapor stream (both pre- and post dilution), effluent from oxidizer, and effluent from quench/scrubber system.

3.2.3 SVE Flow Rates and Influent Vapor Concentrations

The range and average influent VOC concentrations, and flow rates for each demonstration site are summarized on Table 3.1. Influent and effluent vapor sample analytical results and flow rate measurements for each site are included in the analytical data tables presented in Appendix C. A summary for each site is provided below.

The primary chemicals of concern at Site FT-002, Plattsburgh AFB are benzene, TCE, and tetrachloroethene (PCE). The SVE flow rates for individual VE/VWs ranged from 40 to 90 cfm. The influent vapor flow rate to the FTO unit was maintained at 100 cfm. The concentrations of TCE detected in the influent vapor stream ranged from 0 to 120 ppmv, and the average concentration was 20.6 ppmv. The concentrations of total VOCs in the influent vapor samples ranged from 12 to 6,000 ppmv, and the average concentration was 1,397 ppmv.

The primary chemical of concern at Building 181, AFP 4 is TCE. The influent vapor flow rate to the FTO unit was maintained at 105 cfm by using an automated air bleed-in valve. The concentrations of TCE detected in the post-dilution influent vapor stream ranged from 67 to 170 ppmv, and the average concentration was 81.5 ppmv.

The primary chemicals of concern at the SARS site, former Lowry AFB are TCE and its associated degradation products *cis*-1,2-dichloroethene (*cis*-1,2-DCE) and vinyl chloride. PCE, 1,1-dichloroethene (1,1-DCE), and 1,1,1-trichloroethane also are present. The influent vapor flow rate to the FTO unit was maintained at 105 cfm by

TABLE 3.1
FTO TECHNOLOGY DEMONSTRATION TESTING CONDITIONS
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Demonstration Site	Operating- Reporting Days	Days of Actual Operation	Avg. Flow Rate Treated (cfm) ^{c/}	Range of Influent VOC ^{a/} Concentration (ppmv) ^{d/}	Avg. Influent VOC Concentration (ppmv)	Range of Influent TCE ^{b/} Concentration (ppmv)	Avg. Influent TCE Concentration (ppmv)
Plattsburgh AFB ^{e/}	210	139	100	12 to 6,000	1,397	0 to 120	20.6
Air Force Plant 4	180	109	105	60 to 100	81.5	67 to 170	118.8
Former Lowry AFB	104	60	105	3 to 10	8.2	5.1 to 11	7.0

a/ VOC = volatile organic compound, as determined by Air Toxics, Folsom, CA using USEPA Method TO-14 Gas Chromatography/Mass Spectrometer full scan. See Appendix B for Target analyte list. Total VOCs referenced to heptane (molecular weight = 100).

b/ TCE = trichloroethene.

c/ cfm = cubic feet per minute.

d/ ppmv = part per million by volume, as determined by Air Toxics, Folsom, CA using USEPA Method TO-14 GC/MS full scan. See Appendix B for target analyte list.

e/ AFB = Air Force Base.

using an automatic air bleed-in valve. Approximately 80 cfm of the influent vapor flow rate was from the SARS, and approximately 25 cfm was ambient air (oxygen). The concentrations of TCE detected in the post-dilution influent vapor stream ranged from 5.1 to 11 ppmv, and the average concentration was 7 ppmv. The concentrations of total VOCs in the influent vapor samples ranged from 3 to 10 ppmv, and the average concentration was 8.2 ppmv. The influent vapor stream range of TCE is higher than the influent vapor stream range of total VOCs, because the analytical laboratory referenced total VOCs to heptane (molecular weight = 100) instead of a heavier molecular weight compound (e.g., TCE, with a molecular weight of 131.4).

3.3 OBSERVED PERFORMANCE

Site-specific data tables detailing FTO system performance are provided in Appendix C. The following sections provide a summary of contaminant removal rates, contaminant DREs, and reliability and maintainability of the FTO system.

3.3.1 Contaminant Removal Rates

A summary of demonstration results is presented in Table 3.2. During the FTO demonstration at Plattsburgh AFB, a total of 8,162 pounds of VOC vapors were recovered from the soil during 139 days of SVE. During the FTO demonstration at Building 181, an estimated 572 pounds of TCE were recovered from the soil over 109 days of extraction. During the FTO demonstration at the SARS site, an estimated 19 pounds of total VOCs were recovered from the soil over a total of 60 days of extraction. Average removal rates for total VOCs, summarized in Table 3.2, ranged from 0.32 pounds per day (lb/day) at the former Lowry AFB to 59 lb/day at Plattsburgh AFB.

3.3.2 Contaminant Destruction/Removal Efficiencies

DREs for the FTO systems were calculated using the following equation:

$$DRE = \left(\frac{Concentration_{Influent} - Concentration_{Effluent}}{Concentration_{Influent}} \right) \times 100\%$$

Table 3.3 summarizes the average DREs for primary contaminants of concern at each site. The individual contaminant DREs for the majority of the sampling events was greater than 99.9 percent.

The effluent caustic scrubber, which was employed at AFP 4, was effective in removing HCl to a discharge rate of <0.040 lb/hr. The maximum TNRCC allowable emission rate for HCl was 0.0247 lb/hr.

3.3.3 Reliability and Maintainability

During this demonstration, the FTO system proved to be operationally reliable. However, the FTO system was sensitive to external operations when it was connected to other remediation systems (i.e., AFP4 and the former Lowry AFB). The FTO unit shut down once during each of the three demonstrations due to internal system

TABLE 3.2
FTO TECHNOLOGY DEMONSTRATION RESULTS
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Demonstration Site	Pounds of Total VOCs Removed	Avg. total VOC ^{a/} Removal Rate (lb/day) ^{c/}	Treatment Cost (\$)	Treatment Cost Per Pound of		
				Total VOC Removed (\$/lb) ^{d/}	Avg. Total VOC Emission Rate (lb/day)	Operational Efficiency ^{b/} (%)
Plattsburgh AFB ^{e/}	8,162	59	73,934	9.05	0.01	75
Air Force Plant 4 ^{f/}	572	5.2	79,912	139.72	0.01	60
Former Lowry AFB	19	0.32	36,706	1,931.89	0.04	57

^{a/} VOC = volatile organic compound, as determined by Air Toxics, Folsom, CA using USEPA Method TO-14 GC/MS full scan. See Appendix B for target analyte list.

^{b/} Operational Efficiency is defined as the percent of calendar days the system actually operated while on-site. This included downtime due to response time, repair, and restart of the systems.

^{c/} lb/day = pounds of total VOC per day.

^{d/} \$/lb = cost per pound of total VOC removed.

^{e/} AFB = Air Force Base.

^{f/} Trichloroethene (TCE) was the only volatile organic compound (VOC) detected in the influent vapor samples. Therefore, results reported are for TCE.

problems. These problems included malfunction of a thermal couple at AFP4, and malfunction of the flow rate-pressure transducer transmitter at the former Lowry AFB.

TABLE 3.3
AVERAGE CONTAMINANT DESTRUCTION/REMOVAL EFFICIENCIES
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Demonstration Site	Total VOCs ^{a/} percent	Benzene percent	TCE ^{b/} percent	PCE ^{c/} percent
Plattsburgh AFB ^{d/}	99.96	99.98	99.98	99.99
Air Force Plant 4	- ^{e/}	ND ^{f/}	99.99	ND
Former Lowry AFB	98.87	ND	99.97	99.40

^{a/} VOCs = volatile organic compounds.

^{b/} TCE = trichloroethene.

^{c/} PCE = tetrachloroethene

^{d/} AFB = Air Force Base

^{e/} Trichloroethene (TCE) was the only VOC detected in the influent vapor samples.

^{f/} ND = Analyte not detected in influent vapor stream.

At Plattsburgh AFB, the FTO system was operationally available for 156.5 days, or 75 percent of the 210 days onsite. Approximately 19 percent of the downtime was associated with problems internal to the FTO unit. The majority of the down time was due to heavy rains damaging the VFD controller and severe winter weather. Heavy rains caused damage to the variable frequency drive (VFD) controller for the SVE blower on two separate occasions. A redesigned VFD was installed, and the system was operational 96 percent of the remainder of the demonstration period, including 100 percent during February 1997. In January 1997, the FTO system shut down twice due to low supplemental fuel pressure readings caused by very cold (-27°F) ambient temperatures. Increasing the propane pressure-regulator setting alleviated this problem.

At AFP4, the FTO system operated for 109 of 180 days onsite (i.e., was 60 percent available). Approximately 17 percent of the downtime was associated with problems internal to the FTO unit. An oxidizer thermocouple was replaced after its malfunction caused a system shut down. External causes of FTO shut downs included 1) loss of water supply to the quench scrubber; 2) failure of a float switch in the groundwater treatment system (SVEPP) air stripper sump (the discharge point for the scrubber effluent), which caused a high-water level in the FTO quench tank; and 3) propane exhaustion due to the supplemental fuel tank not being filled (by supplier) on schedule. Increasing the scrubber water inlet flow rate on September 10, 1997, addressed the water-pressure fluctuation problem. The system then was 100 percent operational for the remainder of the demonstration period.

At the former Lowry AFB, the FTO system operated for 60.1 of 104 days onsite, with an overall operational run time of approximately 57 percent. Approximately 2 percent of the downtime was associated with problems internal to the FTO unit. Condensate collecting in the 0.25-inch stainless steel tubing connected to the air flow meter transducer transmitter at the inlet to the oxidizer caused two shutdowns of the

FTO unit due to low air flow to the oxidizer. External problems causing FTO unit shutdowns included: 1) power outages at the Base due to severe electrical storms or work being performed on the electrical transmission lines at the Base by an electrical subcontractor; 2) unexpected shutdowns of the SARS, which caused the FTO unit to shut down due to low flow to the oxidizer; 3) shutdowns of the SARS for scheduled maintenance; and 4) high water level in the condensate knockout drum. Additional information pertaining to the nature of these shutdowns is included in the analytical data reports provided in Appendix C.

Regular monthly maintenance requirements for the Thermatrix FTO system are minimal, and Base personnel (technicians) can be trained to perform the regular maintenance. Regular maintenance, which required 1 to 3 hours per week (on site), typically included checking the supplemental fuel supply, checking influent flow rate and oxidizer temperatures, and emptying the condensate knockout drum. If supplemental fuel is supplied from a storage tank, then fuel levels must be monitored, and the tank must be kept full by a supplier to ensure uninterrupted system operation. The condensate knockout tank must be monitored and emptied on a regular basis. If the scrubber is used, it requires regular maintenance/ adjustments and may require an additional 2 to 4 hours per week of monitoring and flow adjustment.

3.4 COST INFORMATION

The costs for the FTO demonstrations are summarized in Table 3.4. The total demonstration costs ranged from \$101,783 at the former Lowry AFB to \$178,237 at Plattsburgh AFB.

One of the objectives of this project was to demonstrate the applicability of FTO technology for SVE off-gas treatment. Therefore, increased system monitoring was conducted at these demonstration sites to compile a database to be used in this technology evaluation. Monitoring costs for FTO systems could be reduced by lowering the frequency at which samples are collected for laboratory analysis.

3.4.1 Cost of Treatment

The cost per day and cost per pound of total VOCs removed were estimated based on a prorated 30-day month, with the capital cost of the FTO unit averaged over an estimated 3-year equipment life. FTO technology demonstration treatment costs included Thermatrix mobilization and startup, treatment unit transportation, propane, electricity, and demobilization. Excluded from these costs are Parsons ES labor costs and the cost of vapor and air emission sampling, which would be relatively consistent for other vapor treatment technologies.

The total treatment cost per day ranged from \$352 (Plattsburgh and former Lowry AFB) to \$443 (AFP 4) per day (Table 3.4). The treatment cost per pound of total VOCs removed during the demonstrations ranged from \$9.05/lb (Plattsburgh AFB) to \$1,931.89/lb (former Lowry AFB) (Table 3.4). The higher unit cost reflects low influent VOC concentrations. Due to the low influent total VOC concentrations (3 to 10 ppmv) at the SARS site at the former Lowry AFB, the FTO system was operating at less than 1 percent of the designed loading rate, which dramatically increased the cost per pound of VOCs removed. At Building 181 at AFP 4, the influent TCE

TABLE 3.4
FTO TECHNOLOGY DEMONSTRATION COSTS
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Interagency WBS # ^{a/}	Cost Item	Plattsburgh AFB ^{b/} Subtotal	Air Force Plant 4 Subtotal	Former Lowry AFB Subtotal
33-07	Capital Costs ^{c/}	\$40,900	\$45,249	\$20,255
33-01-XX-01-05	Transportation of Treatment Unit to Site	\$2,000	\$1,742	\$3,200
33-01-XX-01-05	Thermatrix Mobilization and Startup	\$12,360	\$23,188 ^{d/}	\$8,106 ^{e/}
33-01-XX-01-06	Parsons ES Workplan/Mobilization/Startup Labor	\$36,874	\$27,477	\$38,042
33-14-XX-01-06	Analytical	\$21,073	\$3,930	\$2,931
33-14-XX-01-08	Parsons ES FTO Sampling/ Operating Labor	\$23,738	\$14,946	\$15,496
33-14-XX-01-08	Other Direct Costs ^{f/}	\$21,514	\$13,030	\$5,972
33-14-XX-01-08	Electricity ^{g/}	900	\$1,185	\$606
33-14-XX-01-08	Propane ^{h/}	\$10,777	\$6,810	\$2,076
33-21-XX-01-12	Transportation of FTO Unit From Site	\$2,504	\$1,740	\$2,463
33-21-XX-01-12	Thermatrix Demobilization Labor	\$2,751	\$0	\$0
33-21-XX-01-12	Parsons ES Demobilization Labor	\$2,846	\$1,318	\$2,636
TOTAL DEMONSTRATION COST =		\$178,237	\$140,615	\$101,783
TOTAL POUNDS OF TOTAL VOCs REMOVED =		8,162	512	19
TOTAL TREATMENT COSTS^{i/} =		\$73,934	\$79,912	\$36,706
TREATMENT COST PER POUND OF TOTAL VOCs REMOVED^{j/} =		\$9	\$140	\$1,932
TOTAL DAYS ON SITE =		210	180	104
TOTAL TREATMENT COST PER DAY^{k/} =		\$352	\$443	\$352

a/ USEPA (1995).

b/ AFB = Air Force Base

c/ The capital cost is the total vendor capital cost (not including quench/scrubber at Plattsburgh AFB and the former Lowry AFB) prorated over an estimated 3 year life of the FTO system. Plattsburgh AFB: (\$213,265/1,095 days) x 210 days = \$40,900. AFP 4: (\$275,265/1,095 days) x 180 days = \$45,249. Former Lowry AFB: (\$213,265/1,095 days) x 104 days = \$20,255.

d/ Includes service performed by Thermatrix, Inc. in Knoxville, TN prior to the FTO demonstration at AFP 4, TX.

e/ Includes service performed by Thermatrix at the former Lowry AFB during the week of April 20, 1998.

f/ Other direct costs include travel, per diem, supplies. For former Lowry AFB also includes security alarm and fence.

g/ Excludes power costs for site SVE blower. Plattsburgh AFB assumes \$0.10 per kilowatt hour, AFP 4 assumes \$0.082 per kilowatt hour, and former Lowry AFB assumes \$0.08 per kilowatt hour.

h/ Costs based on actual propane use. Plattsburgh AFB average propane cost of \$1.15 per gallon, AFP 4 average propane cost of \$0.88 per gallon, and former Lowry AFB average propane cost of \$0.60 per gallon.

TABLE 3.4 (continued)
FTO TECHNOLOGY DEMONSTRATION COSTS
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

- i/ Treatment costs calculated based on total days FTO unit was on each site (210 days at Plattsburgh AFB, 180 days at AFP 4, and 104 days at former Lowry AFB), and include Thermatrix mobilization and startup, treatment unit transportation, propane electricity, and demobilization. Excluded from these costs are Parsons ES labor costs and the cost of vapor and air emissions sampling, which would be relatively consistent for other vapor treatment technologies.
- j/ Total treatment cost divided by the total pounds of total VOCs removed.
- k/ Total treatment costs divided by total days on site.

concentrations ranged from 67 to 170 ppmv, and the FTO system operated at only 5 to 10 percent of the designed loading rate. The designed loading rate can range up to 880 lb/day total VOCs, depending on emission limitations established by the regulatory agency and/or whether or not the quench/scrubber is required. The average loading rate for each of the demonstration sites was 58.7 lb/day total VOCs at Plattsburgh AFB, 4.69 lb/day TCE at AFP 4, and 0.32 lb/day total VOCs at the former Lowry AFB.

The effect of influent total VOC concentrations is illustrated on Figure 3.1, where the total treatment cost per pound of total VOCs removed is plotted as a function of the average influent VOC concentration. As seen on the graph, there is an indirect relationship between treatment cost and influent concentrations. An order of magnitude decrease in treatment cost occurs when there is an order of magnitude increase in total VOC influent concentration. As the influent concentration increases above approximately 1,200 ppmv total VOCs, and flow rate is maintained above 100 cfm, the treatment cost per pound decreases below \$10 per pound, which is the cost range at which FTO technology begins to be competitive with other technologies, as discussed in Section 3.4.2. From the data collected during this demonstration project, it could not be determined at what concentration the treatment cost per pound becomes asymptotic (i.e., no significant cost decrease with increased contaminant loading). The asymptotic cost level will occur when the influent vapor system contains sufficient VOC loading to sustain optimum oxidizer temperature without the need for supplemental fuel at a maximum design flow rate.

3.4.2 Comparisons of Costs with Other Technologies

Vendor information was used to compare the FTO technology to other vapor treatment technologies. Figure 3.2 illustrates the cost comparisons as a function of cumulative annual costs for each treatment technology using an estimated full-scale design for each demonstration site. Figure 3.3 illustrates the cost comparisons as a function of cost per pound of total VOCs treated for each treatment technology evaluated for each demonstration site. These comparisons are based solely on vendor information (except Thermatrix FTO), and could vary significantly based on local VOC emissions limits, and system operating efficiency and reliability.

At Plattsburgh AFB and AFP 4, FTO technology was compared to thermal oxidation, catalytic oxidation, and resin-bed vapor treatment technologies for full-scale application at each site. For full-scale application at Plattsburgh AFB (assuming mass removal of total VOCs at 204 lb/day and an influent vapor flow rate of 500 cfm), the estimated costs of treating VOC vapors using the four technologies range from approximately \$1.98/lb to \$3.46/lb over a 1-year operating period, and from \$1.40/lb to \$1.57/lb over 3 years. The costs of the Thermatrix FTO technology at this site were estimated at \$3.41/lb over a 1-year period of operation, and \$1.45/lb over 3 years. Based on vendor information, the most cost-effective vapor treatment technologies for full-scale application at Plattsburgh AFB were thermal and catalytic oxidation units over a 1- to 3-year treatment period. The FTO technology becomes more cost effective if more than 3 years of operation is needed.

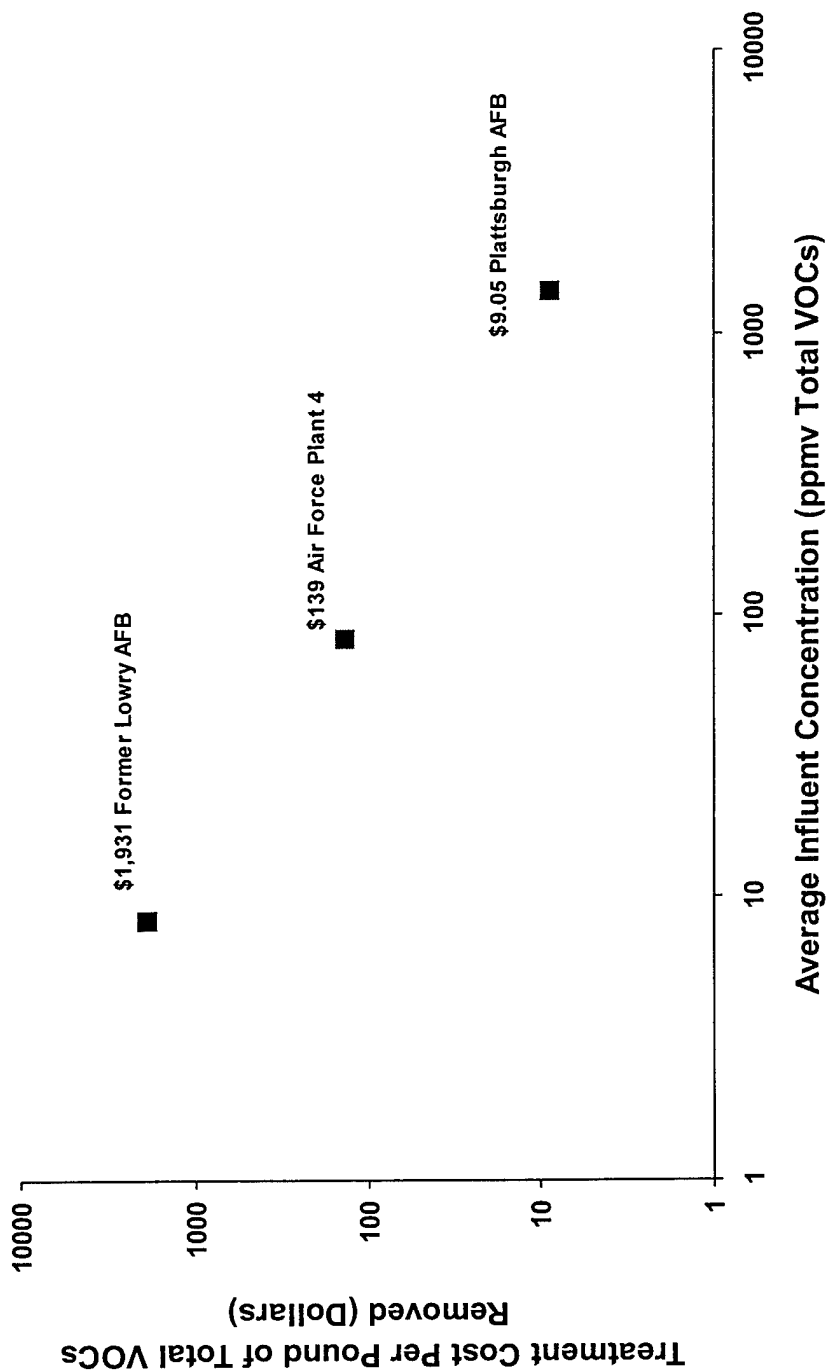


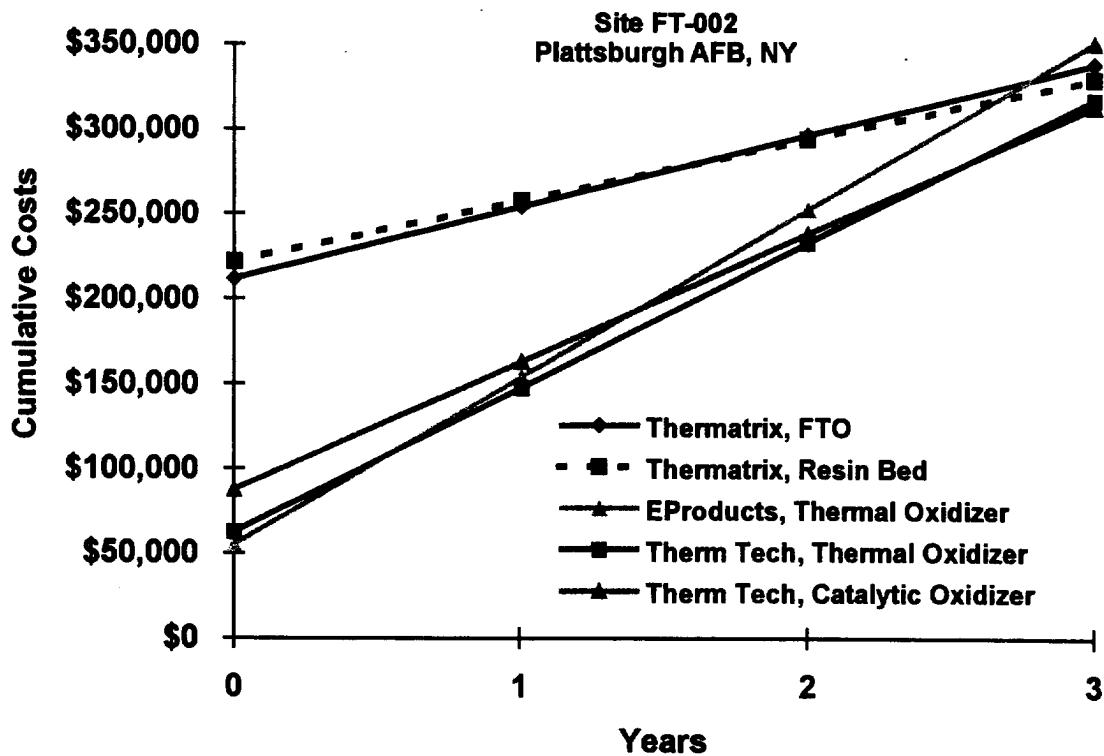
FIGURE 3.1

**COST COMPARISONS OF
TOTAL VOCs REMOVED AS A
FUNCTION OF THE AVERAGE
INFLUENT CONCENTRATION**

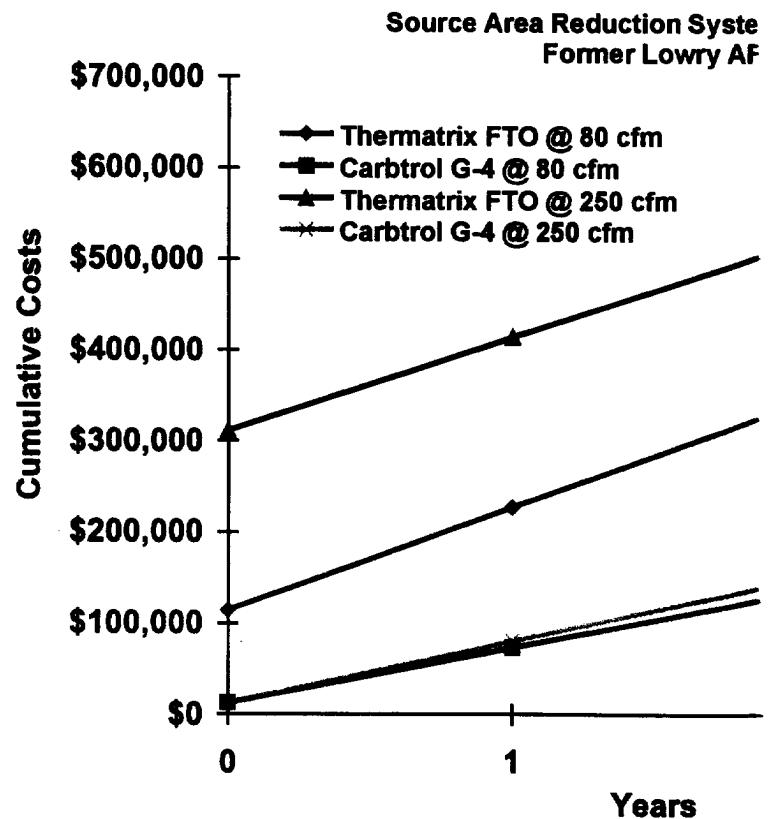
FTO Treatment System Demonstration
Comprehensive Technical Report

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

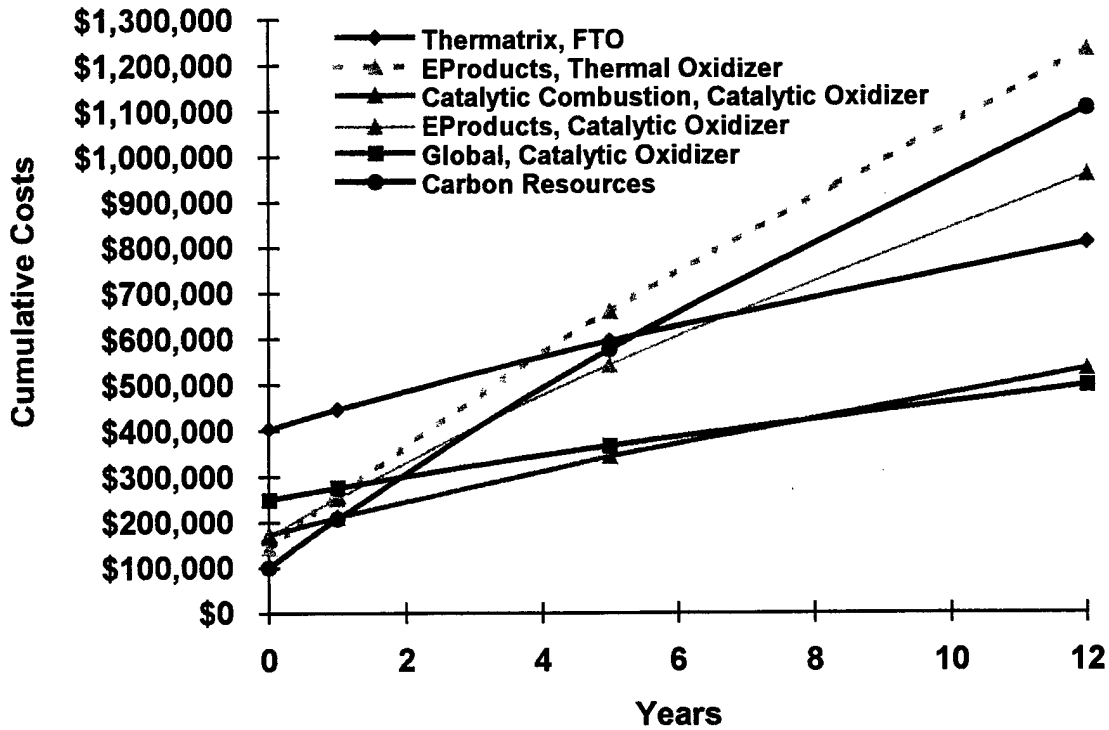


Assumes mass removal of total VOCs at 204 lb/day and
vapor flow rate of 500 cfm



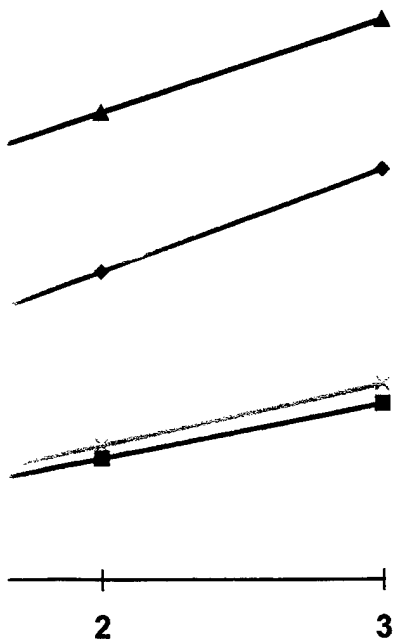
Assumes mass removal of total VOC
vapor flow rate of 80 cfm, and mass r
at 1.76 lb/day and vapor flow r

Building 181
Air Force Plant 4, TX



Assumes mass removal of TCE at 203 lb/day and
vapor flow rate of 1,140 cfm

ystem (SARS) Site
y AFB



l VOCs at 0.58 lb/day and
ass removal of total VOCs
low rate of 250 cfm

FIGURE 3.2

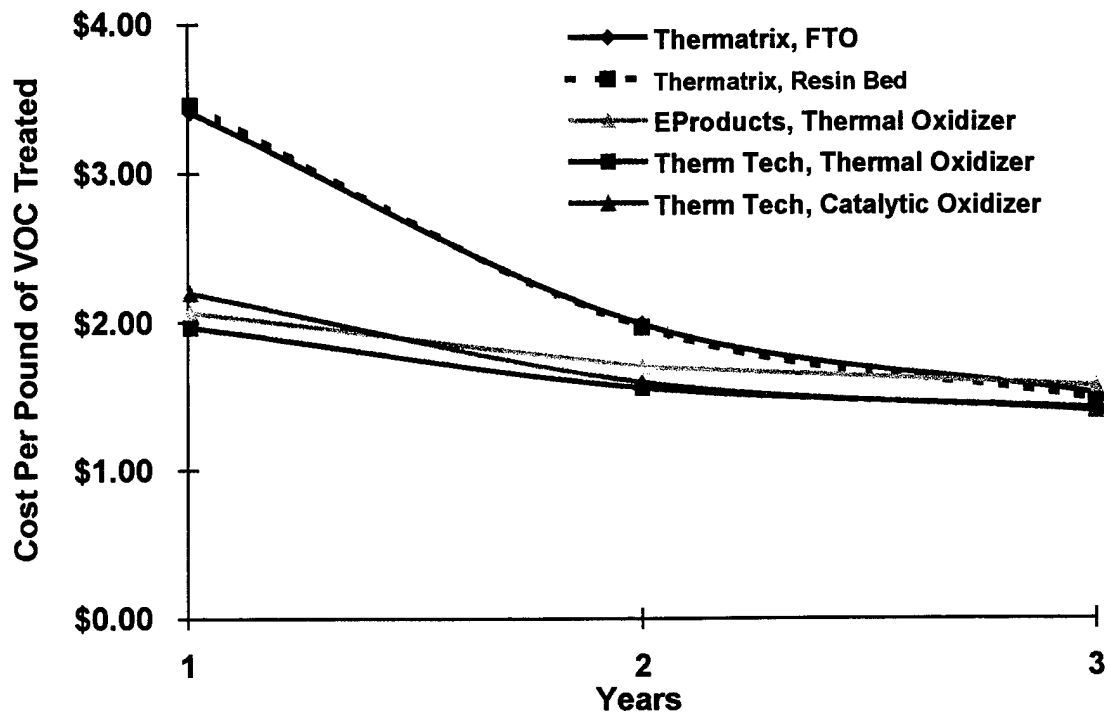
**COST COMPARISONS AS A
FUNCTION OF CUMULATIVE
ANNUAL COSTS**

FTO Treatment System Demonstration
Comprehensive Technical Report

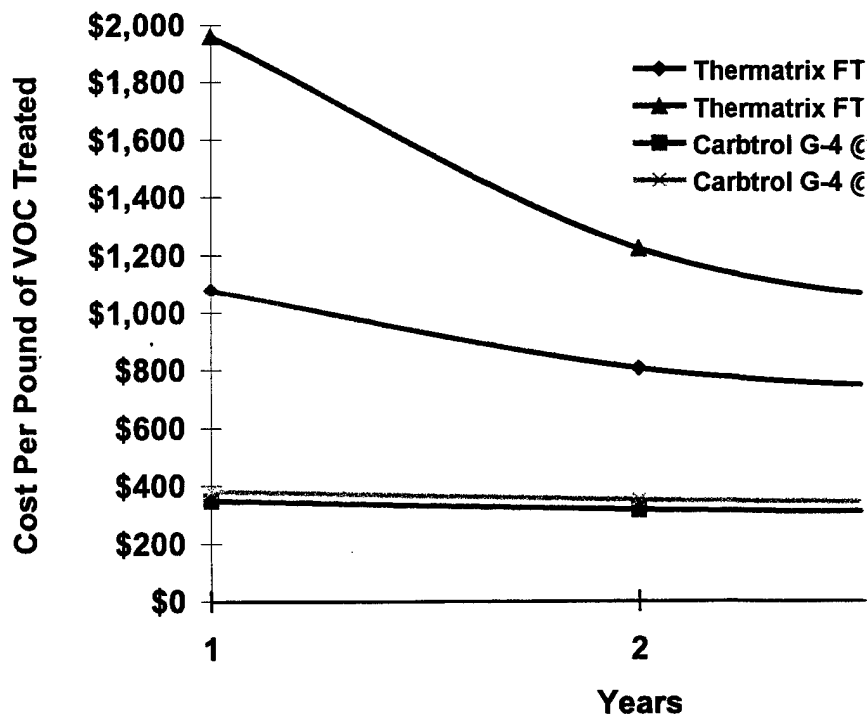
**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

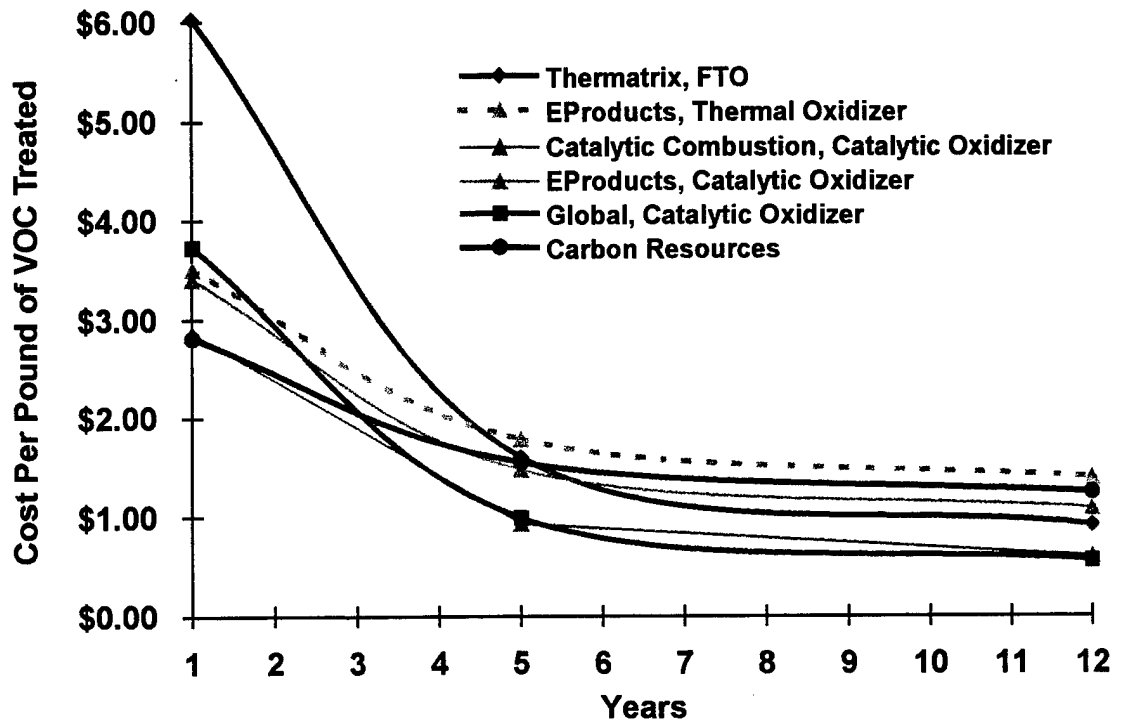
Site FT-002
Plattsburgh AFB, NY



Source Area Reduction System (SARS) :
Former Lowry AFB



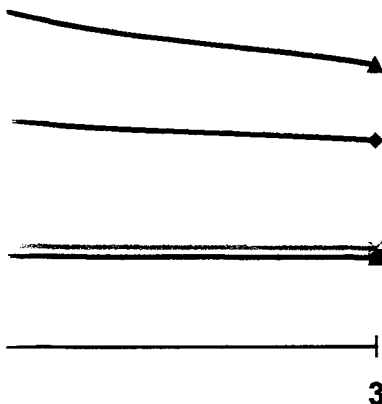
Building 181
Air Force Plant 4, TX



Assumes mass removal of TCE at 203 lb/day and
vapor flow rate of 1,140 cfm

stem (SARS) Site
AFB

Thermatrix FTO @ 80 cfm
Thermatrix FTO @ 250 cfm
Carbtrol G-4 @ 80 cfm
Carbtrol G-4 @ 250 cfm



VOCs at 0.58 lb/day and
ss removal of total VOCs
ow rate of 250 cfm

FIGURE 3.3

COMPARISONS AS A
FUNCTION OF COST PER POUND OF
TOTAL VOCs TREATED

FTO Treatment System Demonstration
Comprehensive Technical Report

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

For a full-scale application at AFP 4 (assuming mass removal of TCE at 203 lb/day and an influent vapor flow rate of 1,140 cfm), the costs of treating TCE vapors using thermal, catalytic, or resin-bed treatment technology may range from approximately \$0.93 to \$1.95/lb over a 5-year operating period, and approximately \$0.56 to \$1.46/lb over 12 years. The costs of the Thermatrix FTO technology at this site were estimated at \$1.60/lb over a 5-year period, and \$0.91/lb over 12 years. The most cost-effective vapor treatment technology for full-scale application at AFP 4 was catalytic oxidation.

At the former Lowry AFB, FTO technology was compared to GAC. Two cost comparisons were made: 1) cost of treatment during the DPE dewatering phase (assuming mass removal of total VOCs at 0.58 lb/day and a vapor flow rate of 80 cfm); and 2) cost of treatment during the DPE treatment phase (assuming mass removal of total VOCs at 1.76 lb/day and a maximum vapor flow rate of 250 cfm). Total costs for treatment using an FTO system are approximately \$454,000 and \$620,000 for 80 and 250 cfm, respectively. Total costs for treatment over a 3-year period using GAC are less than half that of the FTO system (approximately \$194,000 and \$216,000 for 80 and 250 cfm, respectively). Overall, the capital costs for the FTO systems are significantly greater than that of the GAC systems in both DPE operational phases (80 to 250 cfm). The overall operating cost of the FTO is higher due to the need for electricity and/or supplemental fuel, and additional maintenance requirements. Based on the current influent vapor concentrations, the most cost-effective vapor technology for full-scale application at the SARS site is GAC.

Advantages of the FTO technology include:

- Thermatrix developed the FTO process primarily for treating industrial process vapor streams. Therefore, FTO technology is most efficient with steady, moderate to high concentrations and when treatment is required for long periods of time (> 3 years);
- High DRE (typically > 99.99 percent) for VOCs leads to regulatory acceptance;
- Can process batch- or variable-flow vapor streams, maintaining high (> 99.99 percent) DRE;
- Low nitrogen oxide emissions, typically less than 2 ppmv;
- Low carbon monoxide emissions, typically less than 10 ppmv;
- Flameless operation that occurs below the lower explosive limit, and therefore is suitable for installation in Class I, Division 2 hazardous areas;
- Decouples fume mixing from the oxidation reaction, which allows greater flexibility and control, and eliminates products of incomplete combustion (e.g., dioxins and/or furans);
- GS FTO systems can operate with as little as 12 percent inlet oxygen, compared to flame-based systems which require 15 percent oxygen to maintain flame stability;

- Uses a porous inert ceramic matrix that is non-catalytic, non-fouling (inert), and non-hazardous; and
- USEPA does not consider FTO technology an incineration technology. FTO technology is classified as an "other thermal device." Therefore, it is generally easier to permit than thermal oxidation, and should not require continuous emission monitoring (e.g., with an on-line photoionization detector). Such monitoring may be required for flame-based systems, depending on the local regulatory agency requirements.

Disadvantages of FTO technology include:

- Less suited for short-term treatment of low vapor concentrations;
- Higher capital costs than most other oxidation technologies, which results in higher cost per pound of VOCs treated;
- Systems are designed on a site-specific basis, and are not readily available on a short-term rental basis; and
- GS Systems require greater than 12 percent inlet oxygen for optimum efficiency (i.e., to maintain stoichiometric combustion ratios/DREs at >99.99 percent), compared to GAC, which has no minimum oxygen requirement.

SECTION 4

CONCLUSIONS

4.1 TECHNOLOGY PERFORMANCE

The FTO system has proven to be a reliable VOC vapor treatment technology that is capable of maintaining DREs of greater than 99.96 percent. The effluent caustic scrubber, which was employed at Air Force Plant 4, was effective in removing 99.5 percent of HCl, to a discharge rate of <0.040 lb/hr. The maximum allowable emission rate for HCl was 0.0247 lb/hr. The FTO unit shut down once during each of the three demonstrations due to internal system problems, however the majority of the down time was due to external problems.

Based on comparative vendor quotes, the capital costs for the Thermatrix FTO full-scale system were the highest of the technologies evaluated. However, the total annual operating costs were among the lowest of the four technologies considered (with the exception of GAC at Lowry AFB). Therefore, the longer the period of vapor-phase treatment, the more cost-competitive the Thermatrix FTO technology becomes. Thermatrix was the only vendor claiming a VOC DRE of 99.99 percent or greater; other vendor-estimated DREs ranged from 90 to 99 percent. The Thermatrix FTO technology is best suited for high-concentration ($>1,000$ ppmv) VOC vapor streams that contain chlorinated compounds, and where DREs greater than 99.9 percent and/or low nitrogen oxide emissions (i.e., <2 ppmv) are required. Longer operating durations can also favor the economics of an investment in FTO technology. The most appropriate vapor treatment technology for any site will be a function of the site-specific system operating period and the expected changes in soil vapor VOC concentrations over that time period.

4.2 LESSONS LEARNED

The following items summarize the lessons learned during the FTO demonstrations:

- Influent and effluent samples should be collected following the sampling procedures described in the March 13, 1997 letter provided in Appendix B.
- The GS-style FTO unit should include an automated control for monitoring and maintaining influent oxygen concentrations at a minimum of 12 percent using ambient air. The automated oxygen control sensor should be tied into the primary influent vapor line, following the ambient air bleed-in valve, in order to make appropriate adjustments to the oxygen concentration. The October 31, 1996 memorandum in Appendix B provides the rationale for maintaining the influent oxygen concentration above 12 percent.

- For the demonstration FTO unit tested, the flow rate of water to the quench/scrubber system should be maintained between 0.7 and 1.0 gallons per minute to prevent system shutdown due to water pressure fluctuations.
- The discharge from the quench/scrubber system should be tied into a reliable discharge point equipped to handle a continuous discharge.
- Depending on the frequency at which the FTO system will be checked, it may be necessary to increase the condensate collection capacity by adding a second 55-gallon condensate knockout drum. This was done at the former Lowry AFB and the knockout drums were connected with a 0.5-inch ID hose that gravity-fed collected condensate to the lower knockout drum prior to the first drum being filled.
- Extreme ambient cold temperatures (e.g., -27°F) may cause the GS Series FTO system to shut down due to low supplemental fuel (propane) pressure. Increasing the propane pressure-regulator setting during cold temperatures will alleviate this problem.
- FTO units that are supplied with a vacuum blower and that will operate outside should come equipped with a weatherproof starter and electrical box (i.e., National Electrical Manufacturers Association 4).
- If an FTO unit is to be operated outside, direct and continued sunlight can be damaging to programmable-logic controlled LCD screens on the system controller. Therefore, solar protection measures are necessary.
- The unit should be connected to a reliable power source that is not affected by electrical storms, or other systems connected to the same power source.
- The overall cost effectiveness of FTO technology for off-gas treatment is a function of the concentration of the influent vapor stream, the required DRE, and the operational life of the project. SVE remediation using FTO technology is a dynamic process that requires a regular assessment of the system's effectiveness and the need for adjustments (e.g., changing to a new technology when influent VOC concentrations decrease). System replacement depends on project duration and decreases in influent VOC concentrations. Typically, changing to a new technology is not cost-effective during the final phases of treatment.
- As shown at the Plattsburgh demonstration, the FTO technology will be most cost effective for SVE sites with extended high concentrations of soil vapor where high DREs are required.
- A primary objective of this project was to demonstrate the applicability of FTO technology for SVE off-gas treatment. Therefore, increased system monitoring was conducted at these demonstration sites to compile a database that could be used in this technology evaluation. Monitoring costs for FTO systems could be reduced by lowering the frequency at which samples are collected for laboratory analysis, depending on site-specific conditions.

- Relate DREs to temperature, concentrations, and flow rate, which can be monitored continuously.
- Remote adjustment and monitoring options are useful in the operation of SVE systems. The use of remote start-up capabilities requires the completion of a site-specific safety evaluation assessing all possible hazards and consequences (e.g., potential for deleterious effects due to a propane leak going undetected or other changes in site conditions causing a potential hazard) prior to utilizing such a feature. Remote start-up is not available on all Thermatrix FTO units, and could add significant costs to the system capital.
- At closure bases, such as the former Lowry AFB, the FTO unit should be located in a secure area, or enclosed with a security fence that includes woven material to obstruct the view of the unit.

SECTION 5

RECOMMENDATIONS

The Air Force FTO technology demonstration has shown that this technology is effective in treating vapor streams containing VOCs under varying site conditions. The Thermatrix FTO technology is best suited for high-concentration ($> 1,000$ ppmv) VOC vapor streams that contain chlorinated compounds, and where DREs greater than 99.9 percent and/or low nitrogen oxide emissions (i.e., < 2 ppmv) are required. All DoD remediation contractors should be required to evaluate FTO technology as a possible off-gas treatment technology for highly concentrated, chlorinated vapor streams at such sites.

The FTO system used for this demonstration project was transferred to McClellan AFB, California, for use by that base. The tested system's mobility and ability to treat highly concentrated vapor streams suggest that it is generally best suited for initial (0- to 6-months) response at highly contaminated sites where a 100-cfm flow rate will achieve an effective radius of influence to treat contaminated source area soils at the site. The tested FTO system requires 480-volt, 3-phase, 60-amp electrical service. In addition, its applicability should not be limited to SVE technology but should also be considered for treating other vapor streams at contaminated sites (e.g., off-gas from bioslurping systems where both fuel and chlorinated hydrocarbons are present), if VOC concentrations are greater than 1,000 ppmv.

Based on the cost estimates provided in Section 3.4, FTO technology becomes cost-competitive with thermal and catalytic oxidation when influent soil gas VOC concentrations exceed 1,000 ppmv. This comparison will vary depending on site-specific conditions but indicates that FTO technology becomes more cost competitive as influent VOC concentrations, and the duration of vapor-phase treatment, increase. Sites with a large source of VOC vapors (e.g., vapors emitted from concentrated soil residuals or dense nonaqueous-phase liquids) will be the best candidates for the FTO technology. In contrast, sites at which VOC contamination is limited may not be good candidates for the FTO technology, even if initial VOC concentrations are greater than 1,000 ppmv. At sites with a limited initial mass of VOCs, vapor concentrations may be rapidly depleted after a few days or weeks of system operation, causing the FTO technology to consume large quantities of supplemental fuel. Due primarily to the relatively high capital costs of the FTO technology, sites with either low initial VOC concentrations ($< 1,000$ ppmv), or limited initial VOC mass are poor candidates for FTO.

SECTION 6

REFERENCES

- Environmental Science and Engineering, Inc. (ESE). 1994a.
- ESE. 1994b. *Soil Vapor Extraction Pilot Plant Study, Building 181, Fort Worth Texas*. July.
- Hargis & Associates, Inc. (Hargis). 1992. *Soil and Groundwater Assessment, Building 181, US Air Force Plant 4. General Dynamics, Inc. Fort Worth, Texas*.
- Jacobs Engineering Group, Inc. (Jacobs). 1997. *Draft Remedial Design Work Plan, Air Force Plant 4, Fort Worth, Texas*. July.
- Meltzer, J.S. 1992. *Flashback Testing of Thermatrix ES-60H Oxidizer*. Report No. SSR-1628, Fenwal Safety Systems, Inc., Marlborough, MA.
- NYSDEC. 1996. New York State Department of Environmental Compliance Air Regulations, Part 201, Permits and Registrations, Unofficial Transcript, October.
- Parsons Engineering Science, Inc. (Parsons ES). 1995.
- Parsons ES. 1996a. *Final Work Plan for the Evaluation of Flameless Thermal Oxidation at Air Force Plant 4, Fort Worth, Texas*. January.
- Parsons ES. 1996b. *Final Work Plan for the Evaluation of Flameless Thermal Oxidation at Plattsburgh Air Force Base, New York*. March.
- Parsons ES. 1997. *Final Site-Specific Technical Report for the Evaluation of Thermatrix GS Series Flameless Thermal Oxidizer for Off-Gas Treatment of Soil Vapors With Volatile Organic Compounds at Site FT-002, Plattsburgh Air Force Base, New York*. June.
- Parsons ES. 1998a. *Final Work Plan for the Evaluation of Flameless Thermal Oxidation at Former Lowry Air Force Base, Colorado*. January.
- Parsons ES. 1998b. *Final Site-Specific Technical Report for the Evaluation of Thermatrix GS Series Flameless Thermal Oxidizer for Off-Gas Treatment of Trichloroethene Vapors at Building 181, Air Force Plant 4, Texas*. February.
- Parsons ES. 1998c. *Final Site-Specific Technical Report for the Evaluation of Thermatrix GS Series Flameless Thermal Oxidizer for Off-Gas Treatment of Soil Vapors With Volatile Organic Compounds at the Source Area Reduction System, Former Lowry Air Force Base, Colorado*. November.

Thermatrix, Inc. 1992. Destruction of Organic Compounds in the Thermatrix Flameless Thermal Oxidizer. San Jose, California.

US Environmental Protection Agency (USEPA). 1995.

Versar, Inc. 1995. *Draft Preliminary Site Characterization Summary Report Operable Unit 5, Groundwater, Lowry Air Force Base, Colorado.*

Versar, Inc. and Remediation Technologies, Inc. 1996. *Draft Final Lowry Air Force Base Source Area Reduction System Field Pilot Study Implementation Plan.* December

APPENDIX A
VENDOR INFORMATION

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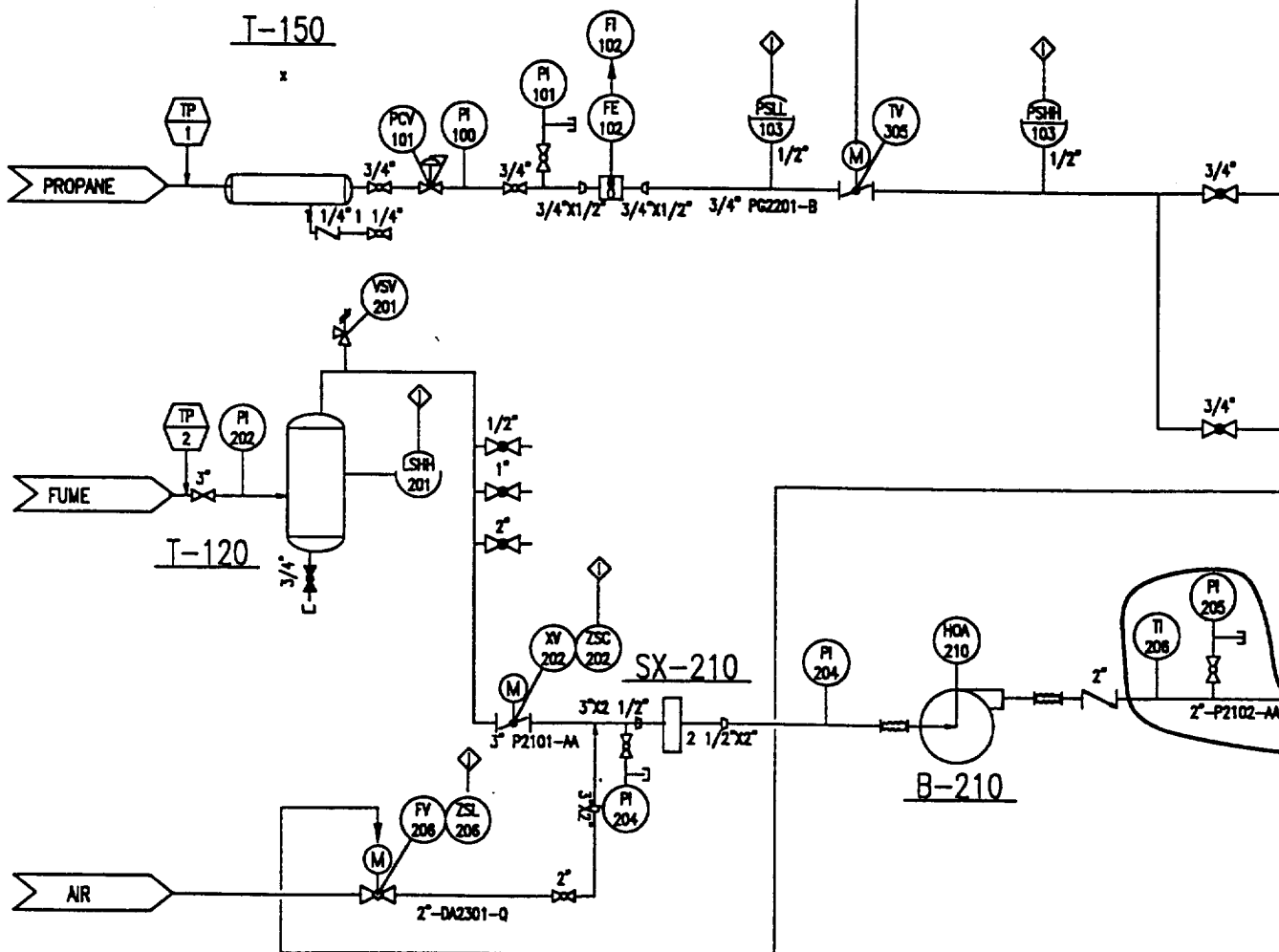
SX-210
FILTER/SILENCER

T-120
K.O. POT

T-150
PROPANE TANK

B-210
AIR/FUME BLOWER
3" X 3"

SX
SP



NOTES:

1. AREA CLASSIFICATION IS GENERAL SERVICE
2. INSTRUMENT AIR IS NOT AVAILABLE
3. ESD KILLS ALL SKID OPERATIONS

(1)

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SX-240

SPARGER

MX-280

STATIC MIXER

R-330

PREHEATER

R-310

THERMAL OXIDIZER

DX-500 A/B

BLIND AND GOGGLE

DX-510 A/B

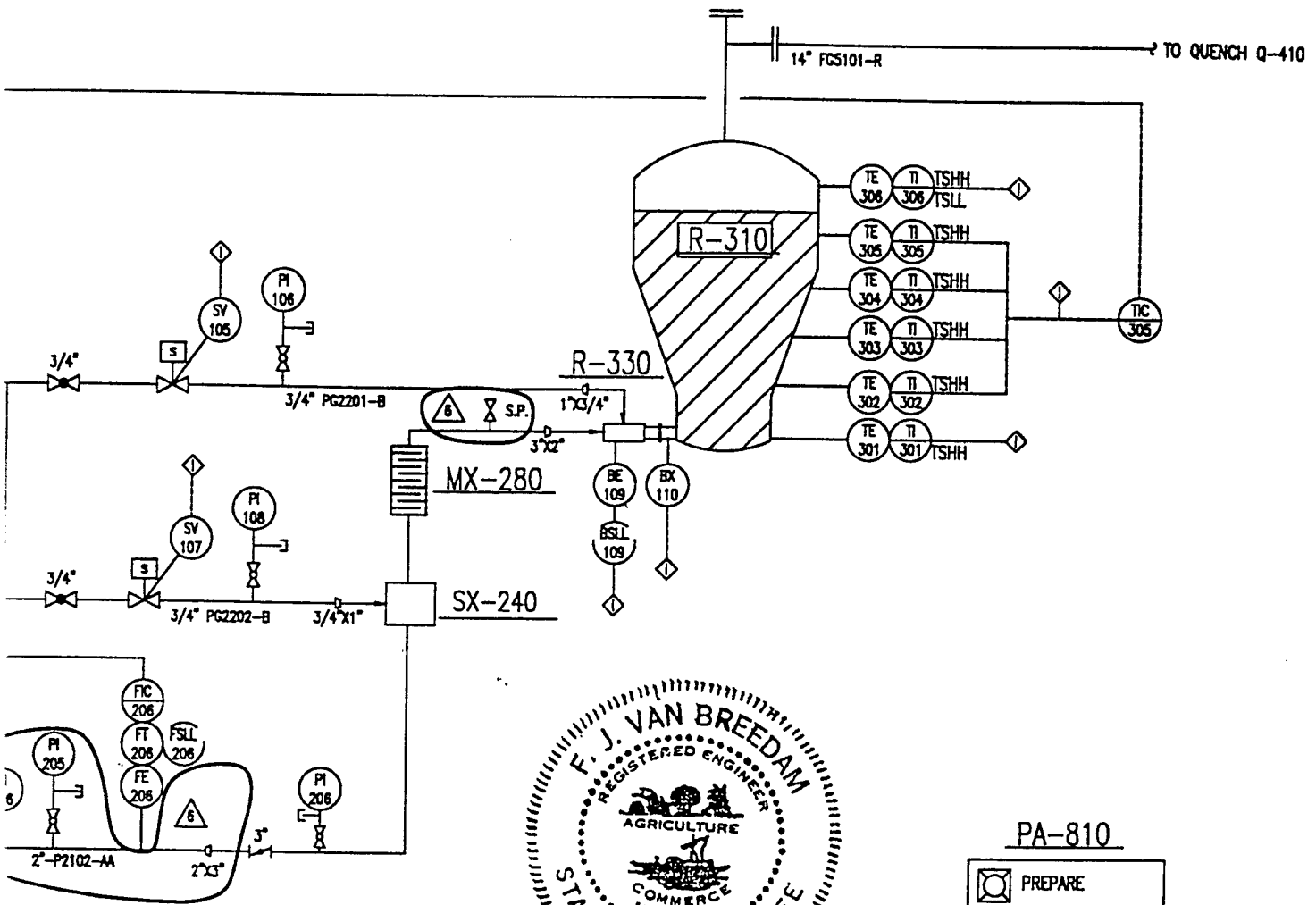
CROSSOVER DUCT

PA-810

CONTROL PANEL

DX-500 A/B

DX-510 A/B



F. J. Van Breedam
11/7/96

PA-810

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5	MECHANICAL REVISIONS	7-19-96	CB2
4	MECHANICAL UPDATES	2-8-96	CB2
3	CLIENT AND ENGINEERING CHANGES	1-23-96	JAN
2	ENGINEERING REVISIONS	11-28-95	JAN
1	REVISED PER CLIENT COMMENTS	11-09-95	JAN
0	INITIAL RELEASE	11-01-95	JAN
E.C.N.	REV	DESCRIPTION	DATE

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OFFICER OF THERMATRIX INC.

THERMATRIX
SAN JOSE, CA 95134
KNOXVILLE, TN 37922

PARSONS, DENVER, CO

PIPING AND INSTRUMENTATION DIAGRAM

DATE 10/17/95
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SHEET 6 OF 6

T-410
QUENCH TANKSX-411A
QUENCH NOZZLEEX-520
EXPANSION JOINTQ-410
QUENCH WEIRFX-411A
FLEX CONNECTORFX-411B
FLEX CONNECTORSX-411B
QUENCH NOZZLEFX-410A/B
FLEX CONNECTORQH-410
QUENCH

FROM OXIDIZER R-310

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EX-520

Q-410

FX-410A/B

SX-411A

FX-411A

SX-411B

FX-411B

QH-410

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DRAIN

2"-PW4206-Z

NOTE 1

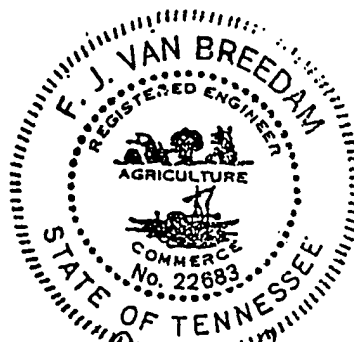
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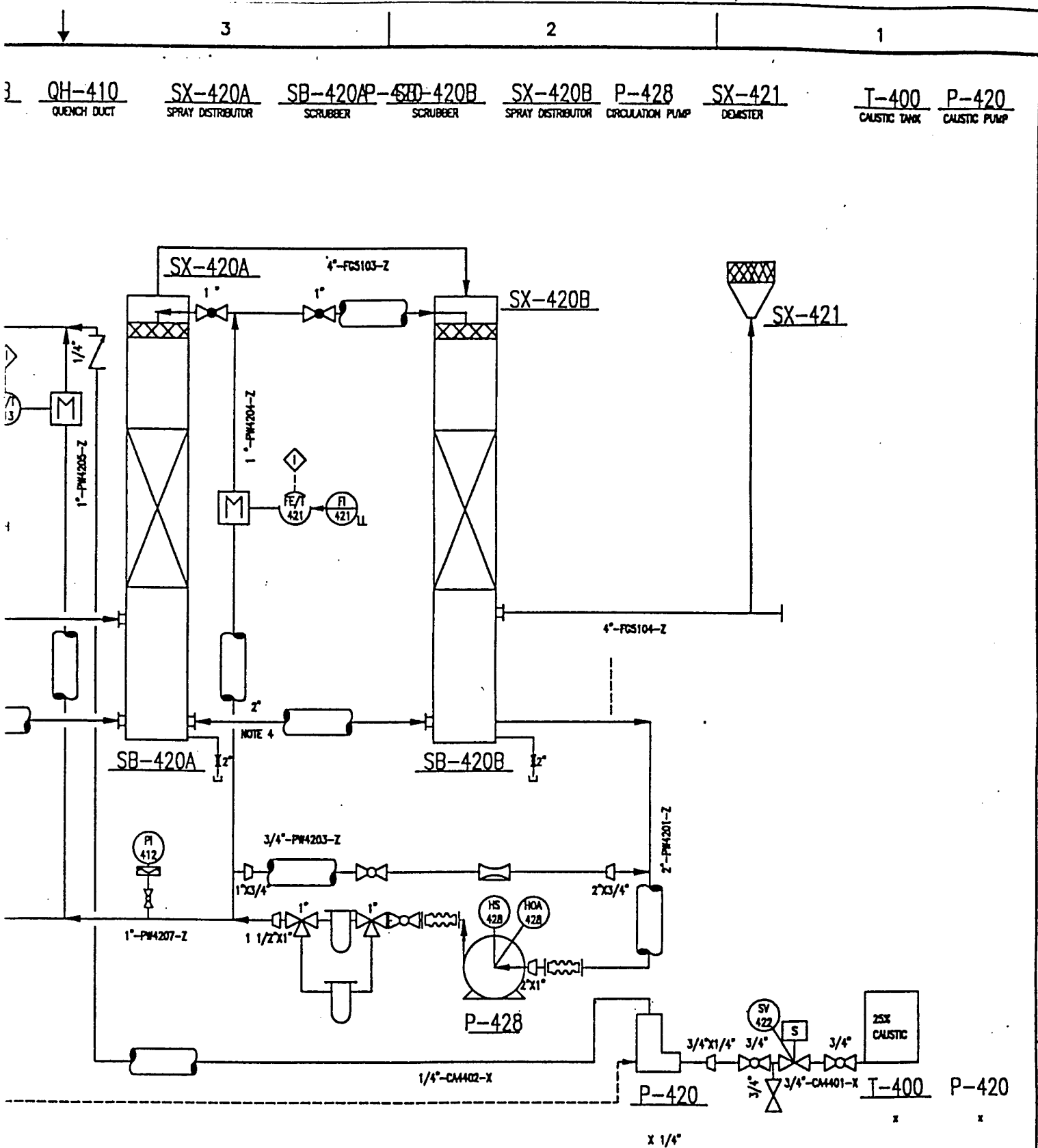
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NOTES:

1. SEAL LEG OVERFLOWS AT HIGH LEVEL
2. INSTRUMENT AIR IS NOT AVAILABLE
3. COMMON SUMP TIE LINE
4. AREA CLASSIFICATION IS GENERAL SERVICE



F. J. Van Breedam
12/4/96



6	AS BUILTS	10-26-96	CB2
5	MECHANICAL REVISIONS	7-19-96	CB2
4	MECHANICAL UPDATES	2-8-96	CB2
3	CLIENT AND ENGINEERING REVISIONS	1-23-96	JAN
2	ENGINEERING REVISIONS	11-28-95	JAN
1	REVISED PER CLIENT COMMENTS	11-09-95	JAN
0	INITIAL RELEASE	11-01-95	JAN
E.C.N.	REV	DESCRIPTION	DATE

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PIPING AND INSTRUMENT DIAGRAM		CHECKED BY JO DATE 11-1-95	DATE 11-1-95
J-3780-000-P402		APPROVED BY JAN DATE 11-1-95	DATE 11-1-95
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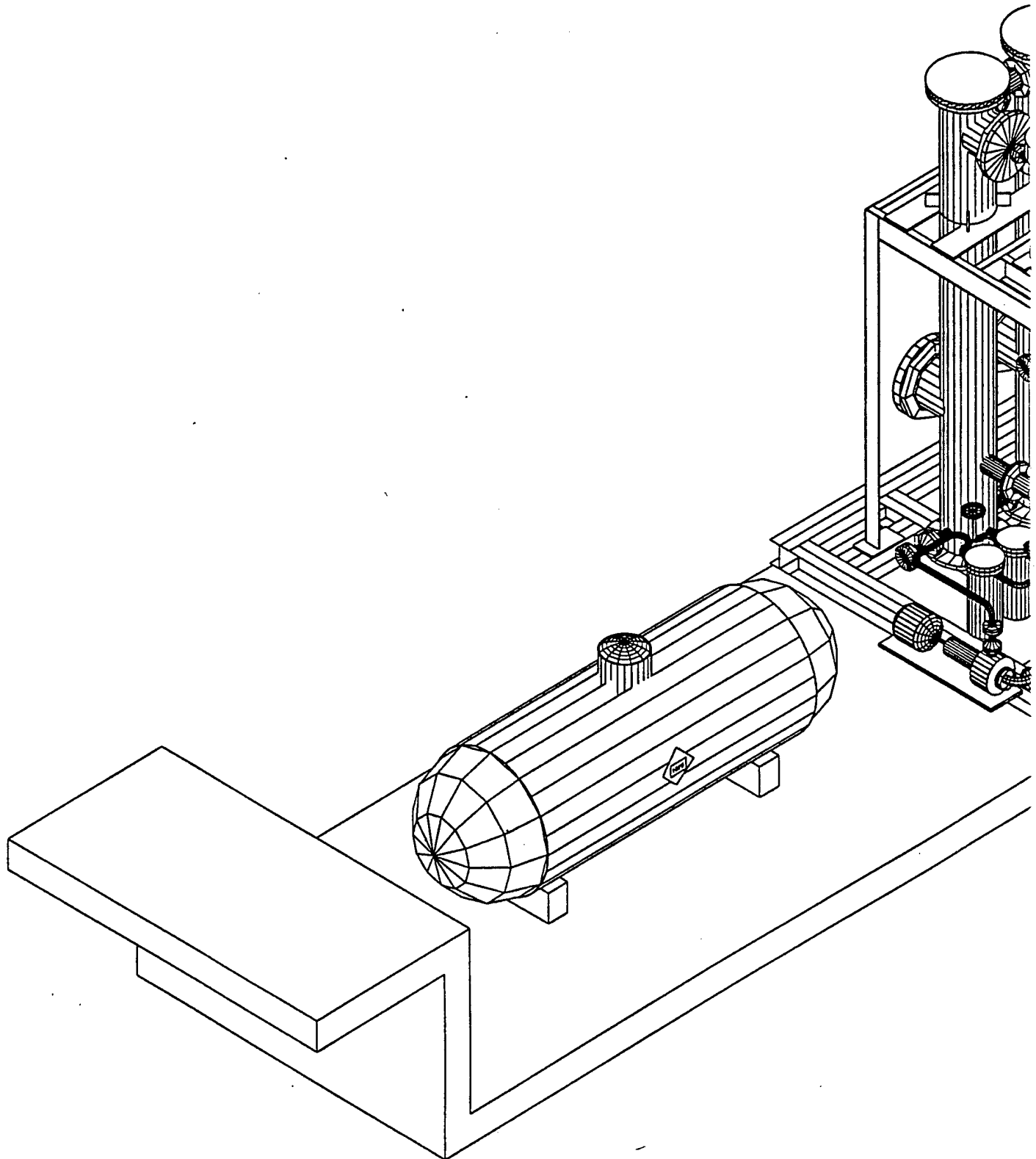


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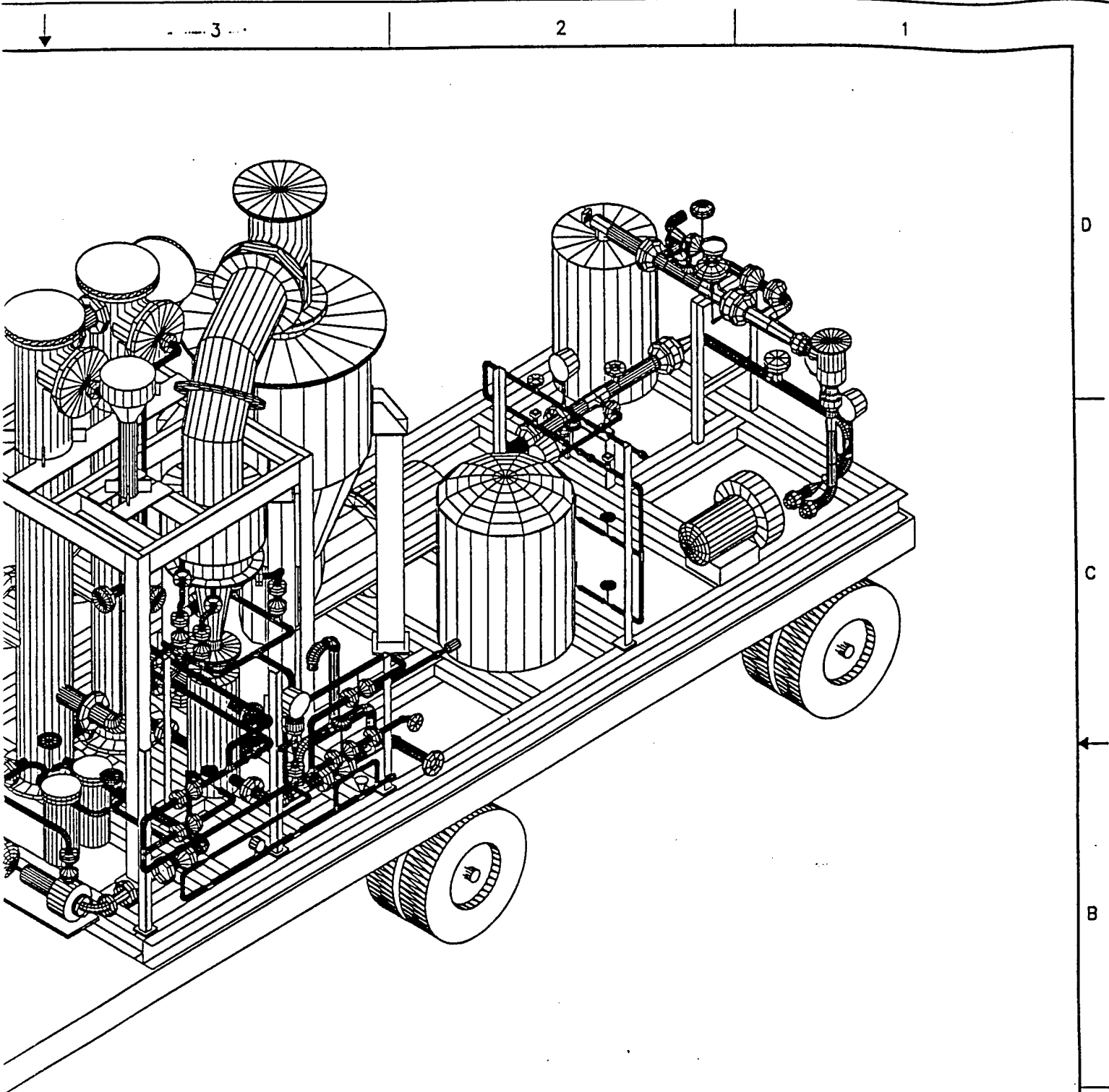
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(1)



2	ADDED PROPANE TANK	11/13/96	
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E.C.N. REV.	REVISION DESCRIPTION	DATE	APV

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THERMATIX SAN JOSE, CA 95134 KNOXVILLE, TN 37922			
PARSONS/USAF MOBILE UNIT			
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SIZE D	COPYRIGHT 1996	DRAWING NO. J-378-000-M71	REV. 2
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(2)

Halogenated VOC Abatement

FLAMELESS THERMAL OXIDATION

INTRODUCTION

A major chemical company has installed (1995) and is operating a Thermatrix flameless thermal oxidation system for treatment of methylene chloride emissions from herbicide production. Prior to this installation, traditional flame-based technology was the corporate standard for this application.

PROCESS DESCRIPTION

The herbicide manufacturing process consists of various unit operations that continuously or intermittently vent process gases containing chlorinated VOCs. The combined vent stream includes 275 pounds per hour methylene chloride, six pounds per hour CO, and traces of methanol, formaldehyde and dichloromethyl ether. Venting results from equipment de-pressurization, controlled process venting, equipment purges, batch chemical transfers and normal breathing losses. Vents are collected and routed to the Thermatrix system for treatment.

THERMATRIX SYSTEM DESCRIPTION

The skid-mounted, fully automated abatement system consists of a Thermatrix reactor and an effluent gas quench which feeds directly to a pre-existing scrubber system. The system is designed for a total flow of 1500 scfm. Prior to shipping, the system was preassembled and modularized to the extent possible to minimize on-site installation work scope.

The system is fed by two vent collection headers which are combined immediately prior to entering the main fume line. Both streams are water saturated, with one containing high concentrations of VOCs inerted with nitrogen to reduce flammability. The second stream contains relatively low concentrations of VOCs and is continuously purged with air.

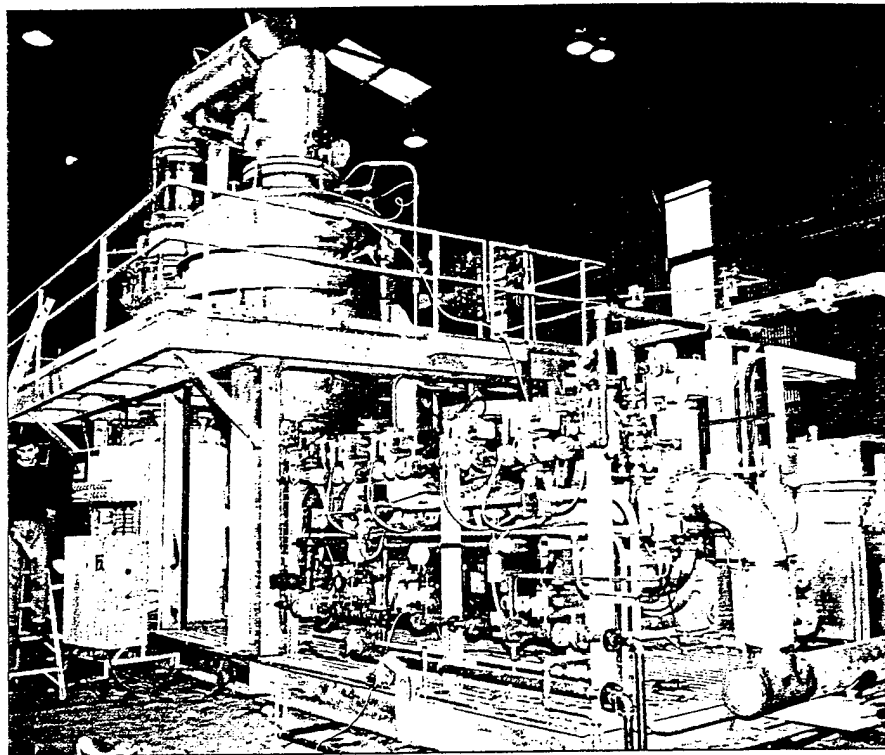
During operation, combustion air is added to the combined vent streams in the main fume line to maintain a minimum oxygen concentration. The premixed fume is then introduced to the Thermatrix reactor, where the organics are oxidized to carbon dioxide and water vapor. An acid gas (HCl) is produced and quenched, then sent directly to a pre-existing caustic scrubber for neutralization. All materials of construction are appropriate for the processing of corrosive gases.

INSTALLATION, COMMISSIONING & PERFORMANCE TESTING

On-site installation was completed in less than 6 days. Performance testing and analysis were performed by a laboratory using EPA test protocol methods 18 and 25. Inlet samples containing up to 300 ppm of total hydrocarbons were taken from the main fume line. Outlet samples collected at the stack revealed undetectable hydrocarbons at a 1 ppm detection limit.

A TOTAL SOLUTION

This Thermatrix application has been field proven to be safe, economical and effective. Direct comparison with alternative technologies reveals similar capital costs with significantly lower operating costs, higher DRE, and improved on-line availability. The demonstrated advantages of the technology helped facilitate the permitting process while providing a total solution for this client's "hard to treat" CVOC abatement application.



FLAMELESS THERMAL OXIDIZER SYSTEM FOR HERBICIDE PLANT CVOCs
FULLY AUTOMATED, HIGH ALLOY REACTOR WITH QUENCH
1500 SCFM TOTAL FLOW

Thermatrix Inc.

...Technology Beyond Compliance

Flameless Thermal Oxidation

TECHNOLOGY BEYOND COMPLIANCE

COST EFFECTIVE TECHNOLOGY INTEGRATION

Flameless Thermal Oxidation can be effectively utilized over a wide range of organic abatement applications. The unique advantages of the technology make possible cost saving emission control approaches not traditionally associated with VOC abatement. The safety and scalability of the flameless Thermatrix device allows for placement in flameproof areas treating smaller, more concentrated point sources. This, coupled with high DREs, can often significantly reduce the total volume of emissions treated while still attaining overall emission reduction goals.

FLAMELESS THERMAL OXIDATION ADVANTAGES:

- Guaranteed 99.99% DRE, including halogenated organics
- Ultra low NOx... less than 2 ppm
- Destructive process produces no secondary organic waste stream
- Energy efficient operation, self-sustaining down to 10 BTU/cf³ in fume
- Approved for classified areas... can be located directly at emission source
- Stable operation when responding to variable organic loading
- Matrix is completely inert, with no catalysts to foul
- Superior turndown capability better addresses minimum baseload conditions, reducing operating costs
- Easily permitted... no continuous emission monitoring required
- Creates potential for emission credits

THE TOTAL SOLUTION

Thermatrix has the engineering experience and expertise to provide a total solution to your environmental problem. We specialize in full-scale, "turnkey" VOC abatement systems.

Thermatrix systems are simple, robust, highly efficient and can provide unique cost savings not possible with more traditional emission control approaches. In many industrial applications, life cycle costs have been field proven to be significantly lower than alternative solutions. Whether you need to replace an existing, more expensive technology or control new emissions from expanding production, call us today and let Thermatrix cost effectively take you to the next level...*beyond compliance.*

Thermatrix Inc.

...Technology Beyond Compliance

Thermatrix Technology Description

FLAMELESS THERMAL OXIDATION

TECHNOLOGY BEYOND COMPLIANCE

Thermatrix Inc. has developed an innovative technology which has been field proven to consistently achieve VOC and HAP destruction/removal efficiencies (DREs) of 99.99% or greater. This unique, flameless technology provides safe, cost effective treatment of a wide range of industrial pollutants. Only the Thermatrix process is able to guarantee greater than 99.99% destruction efficiencies *and* ultra low NOx emissions, typically below 2 ppm.

Thermatrix technology exhibits significant advantages over traditional treatment technologies. These advantages allow our clients to take a fundamentally different approach to process emission control. Thermatrix systems, due to their safety and stability, can be located directly in the client's process at the source of emission. This cost effective, pollution prevention approach can dramatically reduce the volume of emissions treated while achieving maximum reduction in overall emissions. Cost savings are realized by the installation of smaller, more energy efficient systems while the high DRE can favorably influence emission averaging and even provide emission credits.

In the Thermatrix process, organic compounds are oxidized in an inert ceramic bed, without flames or catalysts, into harmless carbon dioxide and water vapor or easily neutralized acid gases. While traditional flame-based thermal oxidation relies on the flame for both fume mixing and reaction, the Thermatrix process completely decouples fume mixing from the oxidation reaction. This allows greater flexibility and control and eliminates products of incomplete combustion (PICs). The absence of catalysts also avoids any chance of poisoning or sintering the matrix.

THE MATRIX

The basis for the Thermatrix process is a "porous inert matrix." This matrix fosters conditions necessary to establish a very efficient and stable reaction zone, allowing flameless oxidation of organic compounds outside their respective flammability limits. The rate of oxidation in this matrix is much faster than with traditional treatment technologies, rendering residence time a non-factor. Also, in contrast to catalytic oxidizers, pressure drop across the system is very low due to the high void space ratio (70%) in the matrix.

The three primary attributes of the porous inert matrix that promote flameless oxidation are its interstitial geometry (enhances mixing), thermal inertia (promotes stability), and surface characteristics (augments heat transfer). The thermal properties of the matrix allow the pre-reaction area, or "mixing zone," to be near ambient temperature while the reaction zone is at the appropriate oxidation temperatures.

The properties of the matrix allow for very effective abatement of halogenated organics. Halogenated organics do not effect destruction efficiency or system life, as appropriate corrosion resistant materials are used for each application. Post-reactor acid gas scrubbing can be provided as needed.

Maximum temperatures in the reaction zone remain well below those of a flame, resulting in extremely energy efficient operation with very low formation of thermal NOx. Using a porous inert matrix to support the oxidation reaction results in several performance, safety and process control related advantages.

Thermatrix Inc.

...Technology Beyond Compliance

THE PROCESS

During initial startup of the unit, the matrix is pre-heated and the desired temperature profile is established. Once in profile, the preheater is completely isolated from the system and fume processing can begin. As the fume enters the ambient mixing zone of the reactor, turbulence intimately mixes the hydrocarbons and air. The ambient mixing zone, with its large thermal mass, adds to the safety of the system by acting to prevent flashback. As the well-mixed, ambient stream moves through the matrix it is heated to oxidation temperature as it reaches the reaction zone. The matrix design physically forces the entire fume stream to pass through the reaction zone which ensures complete destruction of the organic compounds and results in consistently high DREs. Heat released by the exothermic oxidation reaction is absorbed by the matrix, providing the thermal momentum needed to maintain the process.

Emissions which vary widely in fume flow and concentration, as in batch chemical manufacturing, are ideally suited for the thermally efficient Thermatrix process. Energy, in the form of heat, is stored in the matrix between peaks in organic loading. This "buffering" capability enables the system to efficiently process fume on very short notice without additional energy input. For intermittent operations, such as those which shut down overnight or on weekends, air flow through the insulated reactor is significantly reduced to help maintain appropriate temperature profile. This operational stand-by, or "ready idle" mode, greatly reduces operating costs and prolongs system life by minimizing thermal cycling.

Control of the Thermatrix oxidizer is simple and straightforward. The same thermal inertia that buffers system reaction to fluctuating process conditions also provides ample response time to control the reaction. Process control components maintain desired operating temperatures by managing the heating value (enthalpy) of the incoming fume. For organic rich or oxygen deficient streams, dilution air is mixed with the fume to maintain the matrix at desired operating temperatures; for lean fume streams, supplemental energy is added to maintain the oxidation reaction. The typical process control scheme is a simple temperature loop controlling the addition of air or fuel to the incoming fume stream.

THE TOTAL SOLUTION

Thermatrix has the experience and expertise to provide total solutions for a wide range of environmental problems. We have designed, installed, and successfully operated full-scale, "turnkey" systems for numerous industrial applications.

Thermatrix systems are simple, robust, highly efficient and can provide unique cost savings not available with more traditional emission control approaches. In many industrial applications, life cycle costs have been field proven to be significantly lower than those of alternative solutions. Whether you need to replace an existing, more expensive technology or control new emissions from expanding production, call us today and let Thermatrix cost effectively take you to the next level...*beyond compliance.*

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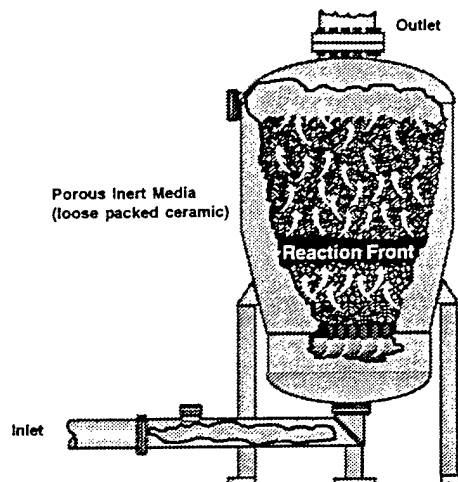
Flameless Thermal Oxidizers for VOC and HAP Control

GS Series: Gas Preheated, "Straight-through" design

Features:

- Guaranteed 99.99% VOC Destruction, including Chlorinated compounds
- Ultra Low NOx...below 2 ppm
- Approved for use in flameproof areas
- Best on fumes with richer VOC concentrations
- Available with top down or bottom up preheat

Typical Applications: Process vents, Wastewater treatment, Remediation, Fuel storage and transfer.

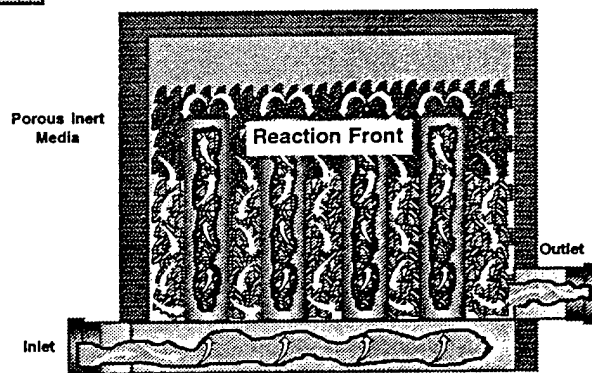


GR Series: Gas Preheated, with "Internal Heat Recovery"

Features:

- Guaranteed 99.99% VOC Destruction, including Chlorinated compounds
- Ultra low NOx...below 2 ppm
- Approved for use in flameproof areas
- Best on fume streams with leaner VOC concentrations

Typical Applications: Process vents, Wastewater treatment, Thermal Desorber off-gas treatment, Paint Booths

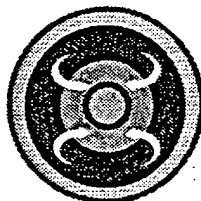


ES Series: Electric Preheated, "Straight-through" design

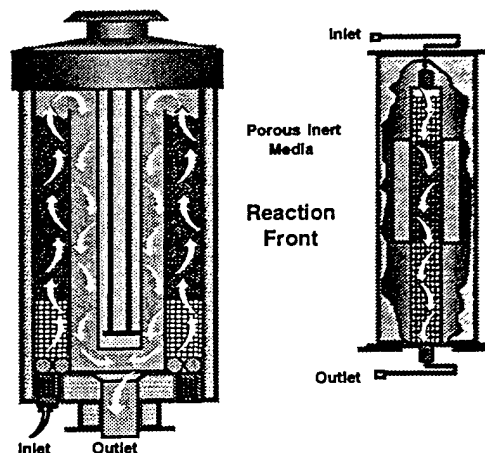
Features:

- Guaranteed 99.99% VOC Destruction, including Chlorinated compounds
- Ultra low NOx...less than 2 ppm
- Approved for use in flameproof areas
- Best on VOC streams below 500 scfm

Typical Applications: Wastewater treatment, Process vents, Fugitive emissions, Remediation



Top View



San Jose, CA
Tel: (408) 453-0490
Fax: (408) 453-0492

Knoxville, TN
Tel: (423) 539-9603
Fax: (423) 539-9643

Mount Laurel, NJ
Tel: (609) 727-5313
Fax: (609) 727-5351

Naperville, IL
Tel: (708) 717-2911
Fax: (708) 717-0284

Houston, TX
Tel: (713) 397-0474
Fax: (713) 580-6720

London, England
Tel: 011 44 71 369 9191
Fax: 011 44 71 361 9192

Applications of Thermatrix Flameless Oxidation Technology in the Treatment of VOCs and Hazardous Wastes

by

Robert G. Wilbourn
Marshall W. Allen
and
Alexander G. Baldwin

Thermatrix Inc.
308 N. Peters Road
Knoxville, Tennessee
(615) 539-9603

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International Incineration Conference
Seattle, Washington
May 8-12, 1995

APPLICATIONS OF THERMATRIX FLAMELESS OXIDATION TECHNOLOGY IN THE TREATMENT OF VOCS AND HAZARDOUS WASTES

Robert G. Wilbourn
Marshall W. Allen
and
Alexander G. Baldwin

Thermatrix Inc.

ABSTRACT

The Thermatrix thermal oxidation technology is a unique, flameless oxidation process that is accomplished in a packed-bed inert matrix. In just over two years of commercial application the technology has been shown effective in destroying a wide variety of organic compounds including chlorinated and sulfonated hydrocarbons. Performance testing conducted to date demonstrates the technology is capable of achieving destruction and removal efficiencies (DREs) in excess of 99.99% with the concurrent production of extremely low quantities of thermal NO_x and carbon monoxide.

The technology has been successfully applied in the treatment of: chlorinated hydrocarbons separated from waste water, fugitive emissions from spray painting operations, and volatile organic compound (VOC) emissions from refinery operations. This year successful treatment and remediation applications of the emerging Thermatrix oxidation technology have been extended. Current technology development and application project activities include: the treatment of VOCs and chlorinated organic compounds separated from contaminated soils, the processing of off-gases containing total reduced sulfur (TRS) compounds, the abatement of chemical vapor releases from manufacturing and refinery operations and on-going technology demonstrations at DOE and DOD sites.

This paper presents and summarizes: current technology development activities, advances in the design of treatment systems based on the Thermatrix thermal oxidation technology, and performance achievements in system operations at multiple project sites.

INTRODUCTION

The Thermatrix technology is a unique, proprietary, patented technology for the flameless thermal oxidation of noxious emissions which arise the normal course of operations in the oil and gas, chemical, pharmaceutical, manufacturing and environmental remediation industries. Thermatrix pioneered its thermal oxidation technology for the highly efficient, controlled, non-flame oxidation of VOCs in a ceramic matrix called a "packed bed".⁽¹⁾ The oxidation of organics occurs in a "reaction zone" contained within the bed of chemically inert ceramic materials typically operated at 1600-1850°F.

In its simplest form, the packed-bed device, shown in Figure 1, consists of an insulated cylinder containing a heated ceramic matrix. In operation, the VOC stream, and any air required to support the oxidation reaction is passed into the bottom of the preheated bed and moves upward through the matrix. The temperature of the incoming gas rises as it picks up heat from the bed until the oxidation temperature of the organic is attained. Once the reaction temperature has been reached, the organics in the VOC stream oxidize creating a stabilized reaction zone as heat is given up to the surrounding matrix. The large thermal mass of the bed also enables it to store or release large amounts of heat without rapid changes in temperature. In many cases the VOC stream may already contain adequate heating value to sustain the bed temperatures. If needed, supplemental energy can be provided from either an electrical heater or by enriching the mixture with natural gas or propane.

Figure 2 schematically presents a basic technology enhancement, i.e., internal oxidation heat recuperation. Heat recuperation in a Thermatrix thermal oxidation unit is accomplished by flowing the incoming and exiting gases counter-currently with metal tube separation.⁽²⁾ In this manner, heat produced during oxidation of the organic constituents is used to raise the temperature of the incoming gas mixture. This style of reactor provides operational and economic process advantages especially in the treatment of highly energetic feed streams, e.g., those streams containing organic compounds in concentrations near the lower explosive limit (L.E.L.).

TECHNOLOGY APPLICATIONS AND TEST RESULTS

Wastewater Treatment

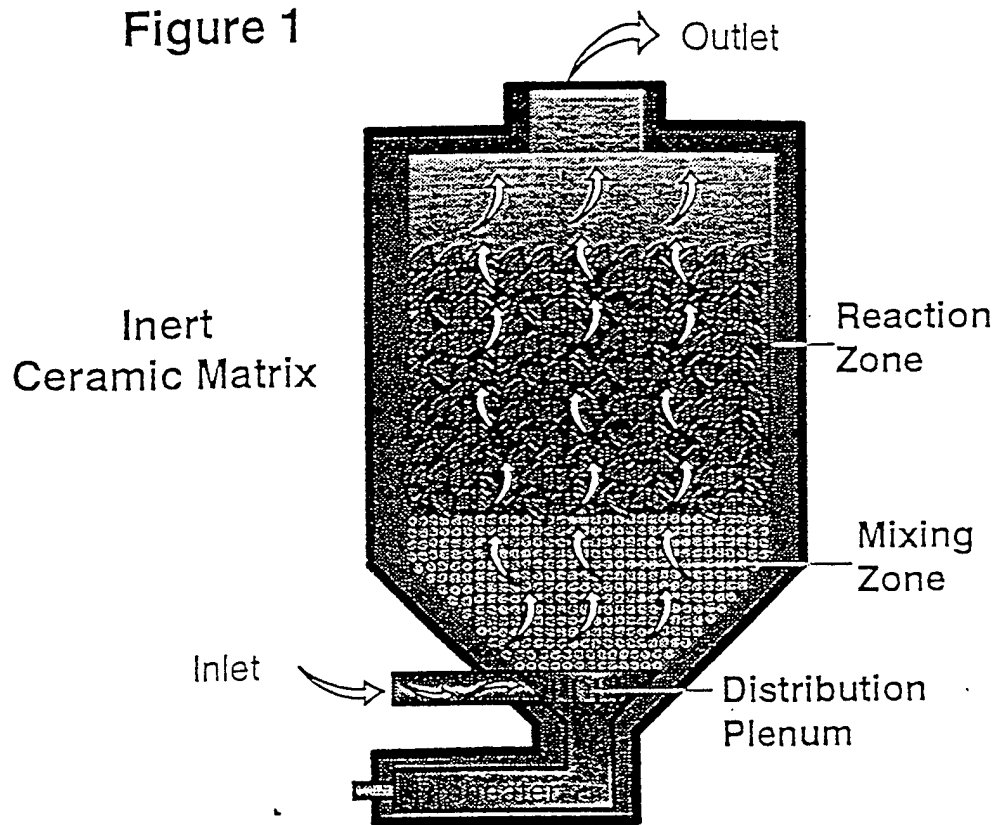
In an effort to voluntarily reduce emissions, a chemical company identified a wastewater stream as a significant source of uncontrolled emissions. The wastewater is generated by steam jet eductors from a vacuum column used in a chemical manufacturing process. The condensed steam from the jet eductors is contaminated with 530 ppmw of ethyl chloride and smaller quantities of butyl chloride, benzyl chloride and non-chlorinated organics, primarily toluene.

The wastewater treatment project was on an extremely aggressive time line to meet corporate emission reduction deadlines. The project scope provided for the design, manufacture, and pre-assembly of a complete unitized, skidded system in less than eight weeks to allow on-site installation, commissioning and start-up to be completed within four weeks.

Thermatrix designed, fabricated and supplied a 100 scfm electrically heated reactor as part of the work scope for this client. The reactor was integrated into an abatement system consisting of an air stripper, knock-out pot, flameless oxidizer, HCl scrubbing system and fully automated controls.

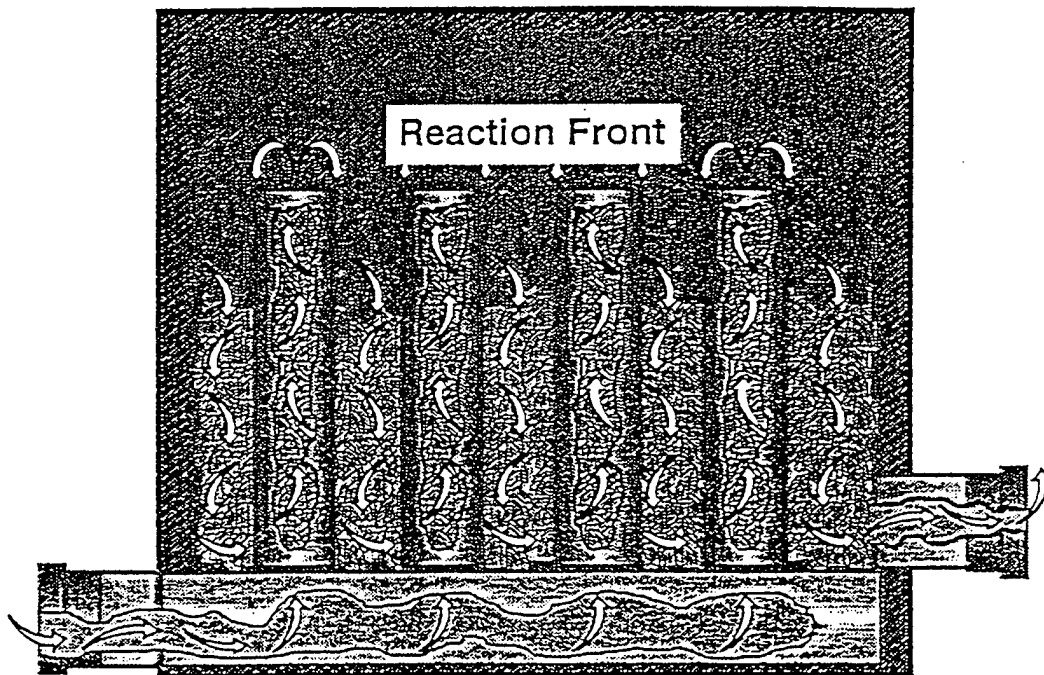
Flameless Thermal Oxidizer

Figure 1



Flameless Thermal Oxidizer with Internal Heat Recovery

Figure 2



Approximately 50 gpm of wastewater is admitted to the air stripping column that is designed to remove 99.9% of the volatiles and produce a moist air stream containing the organics. The cleaned water is recycled to the plant, while the 100-scfm stripper off-gas is conveyed through a knock-out pot and demister before entering the flameless oxidizer, where 99.99% destruction of the organics has been demonstrated achievable. The oxidation reaction produces CO₂, H₂O and HCl. Upon exiting the oxidizer, the gases are quenched and admitted to the scrubbing tower, where 99% of the HCl gas is removed. The scrubber water is discharged from the system to the plant waste water system and the organic-free and acid-free gases exit the scrubber to atmosphere.

To minimize the on-site work scope, the treatment system was designed and pre-assembled complete with all piping, instrumentation and electric power systems. The on-site scope required only completing the few process piping tie ins, terminating a single power feeder and multi-conductor control cable, and erecting the stripping and scrubbing towers which are too tall to be transported in place. Pile foundations, field piping and electrical runs and certain site improvements were completed while the system was being manufactured.

The system was installed, started-up and commissioned without any significant delays. The system has been operating successfully since January 1993. The air permit for the system was issued by state authorities in 30 days.

Refinery Applications

API Separator Emission Treatment

A petroleum refining company contracted with Thermatrix to provide a thermal oxidation system which utilizes a recuperative unit to abate the hydrocarbon emissions from two American Petroleum Institute (API) separators. The project was driven by benzene National Emission Standards for Hazardous Air Pollutants (NESHAP's) for wastewater treatment (40 CFR 61, Subpart FF). A client obtained extension required that the facility be in full regulatory compliance by January 1995.

The project called for Thermatrix to provide a complete skid mounted system with internal heat recovery efficiency of no less than 65%. The thermal oxidation system treats the vapors from several locations in the plant which are manifolded into the suction of two sets of blowers and ducted to the thermal oxidation system. These sources include: two API oil/water separator covers and a number of skimmed oil sumps and slop oil tanks. Figure 3 is a process flow sheet overview of this application.

Thermatrix provided a modularized thermal oxidation system with a stack. Figure 4 shows the system general arrangement. The system is capable of processing 1250 scfm of plant emissions. Preliminary performance results are presented in Table 1 and demonstrate the capability of the system to meet established performance criteria.

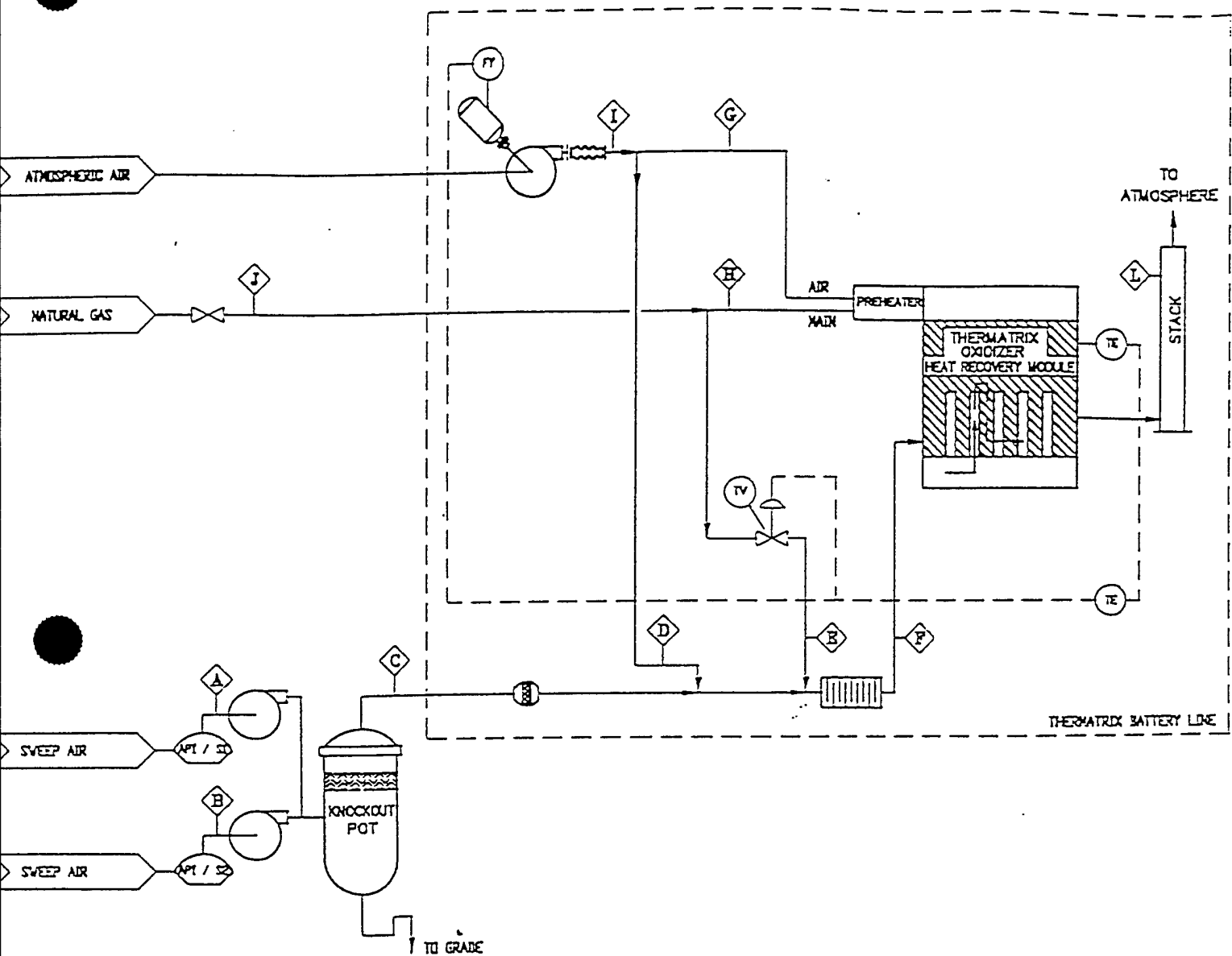


FIGURE 3

REFINERY API SEPARATOR EMISSION TREATMENT
PROCESS FLOW DIAGRAM

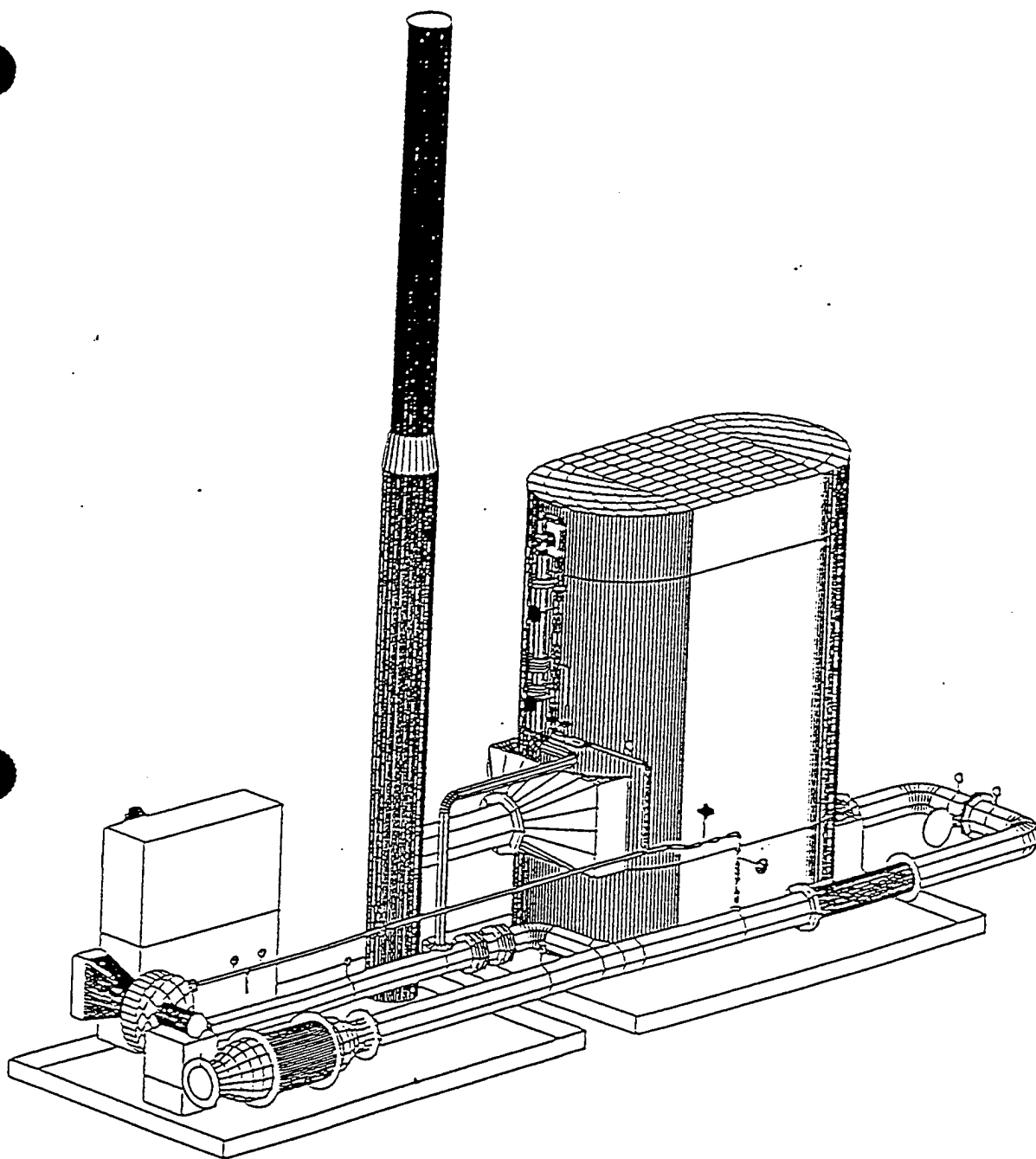


FIGURE 4

REFINERY API SEPARATOR EMISSION TREATMENT SYSTEM
GENERAL ARRANGEMENT

Table 1
Performance Summary
Thermatrix Oxidizer Treating API Separator Emissions

Sample	Total HC (ppmv)	% DRE	CO (ppmv)	%CO ₂	%O ₂	%N ₂	%CH ₄
Inlet	5200		<10	0.091	21	78	0.027
Outlet	(<5) ND	>99.9	<10	2.1	19	79	<0.0002

Oil Recycling

In 1994 Thermatrix supplied a 4000 scfm thermal oxidation unit for use in an oil recycling operation. The client for this unit operates a transportable waste-oil recovery facility that manufactures various grades of fuel oil from waste lubricating oils. The manufacturing process consists of several unit operations including a thermal-cracking reactor that continuously vent process gases containing VOCs. Venting results from entrained air, vaporized waste, light hydrocarbon non-condensable gases and controlled process venting. The incorporation of a Thermatrix unit in the processing system mitigates VOC emissions. Additionally, a finned-tube heat exchanger unit is used to recover heat from the hot Thermatrix off-gas to provide process heating requirements. The heat is transferred to a circulating hot oil stream. The cooler off-gas exiting the heat recovery unit is vented to atmosphere through a stack.

Preliminary test results show the composition of the Thermatrix/heat recovery unit off-gas meets the performance criteria established for the project. Performance data are presented in Table 2.

Table 2.
Performance Summary
Thermatrix Oxidizer Treating Waste-Oil Recycling VOCs

Sample	Total HC (ppmv)	%DRE	CO (ppmv)	%CO ₂	%O ₂	%N ₂	%CH ₄
Inlet #1	6400		34	1.1	19	78	37
Outlet #1	ND (<0.5)	>99.99	ND (<10)	2.9	18	79	ND (0.0002)
Outlet #2	ND (<0.5)	>99.99	ND (<10)	5.1	13	81	ND (0.0002)

Treatment of Pulp Plant Non-Condensable Gases

In the Kraft paper production process a solution containing sodium hydroxide and sodium sulfide is used in the treatment of wood to separate the wood's fiber and lignin components. During pulp plant operations volatile sulfur-bearing VOCs are formed which can be problematic from an emissions control standpoint. A particularly problematic source of sulfur-bearing VOCs associated with paper production is the process non-condensable gases (NCGs) which contain significant quantities of pinene, hydrogen sulfide, methyl mercaptan, dimethyl sulfide and dimethyl disulfide.

In 1994, Thermatrix contracted to deliver a system for the treatment of NCG fumes at a pulp mill. The system is comprised of a gas inlet train, a stainless steel 3000 scfm thermal oxidizer, a quench, a wet scrubber and stack. Figures 5 and 6 schematically present details of the oxidizer and overall system. The system has been installed at the client's site and is currently in the startup and commissioning phase of the project. Initial difficulties were encountered in the startup due to the design placement of the temperature sensing and control thermocouples. These difficulties were largely overcome by relocating the original horizontal thermocouples to a vertical orientation in closer proximity to the reaction zone thereby enabling more accurate temperature monitoring and control.

By the end of February 1995, approximately 400 hours of operation on NCG fumes had been logged. In limited tests the following performance criteria have been demonstrated for the system:

- Destruction and removal efficiency (DRE) for total reduced sulfur (TRS) Compounds > 99.99%
- Sulfur dioxide emission rate of <15 ppm
- Sulfur dioxide (SO₂) removal > 99.96%
- Hydrogen sulfide emission rate < 5 ppm

Treatment of Chemical Plant Chlorinated Volatile Organic Compound Emissions

In January 1995 Thermatrix successfully commissioned a 1500 scfm skid-mounted system consisting of a Hastelloy^(R) oxidizer and a quench/scrubber. The system is currently processing methylene chloride emissions generated during the production of pesticides. The system is designed to provide > 99.99% DRE for chlorinated hydrocarbons.

PARTICIPATION IN DOD AND DOE TECHNOLOGY DEMONSTRATION PROGRAMS

The Thermatrix thermal oxidation technology is currently being demonstrated in two government-sponsored innovative technology demonstration programs. The elements of these programs are presented below:

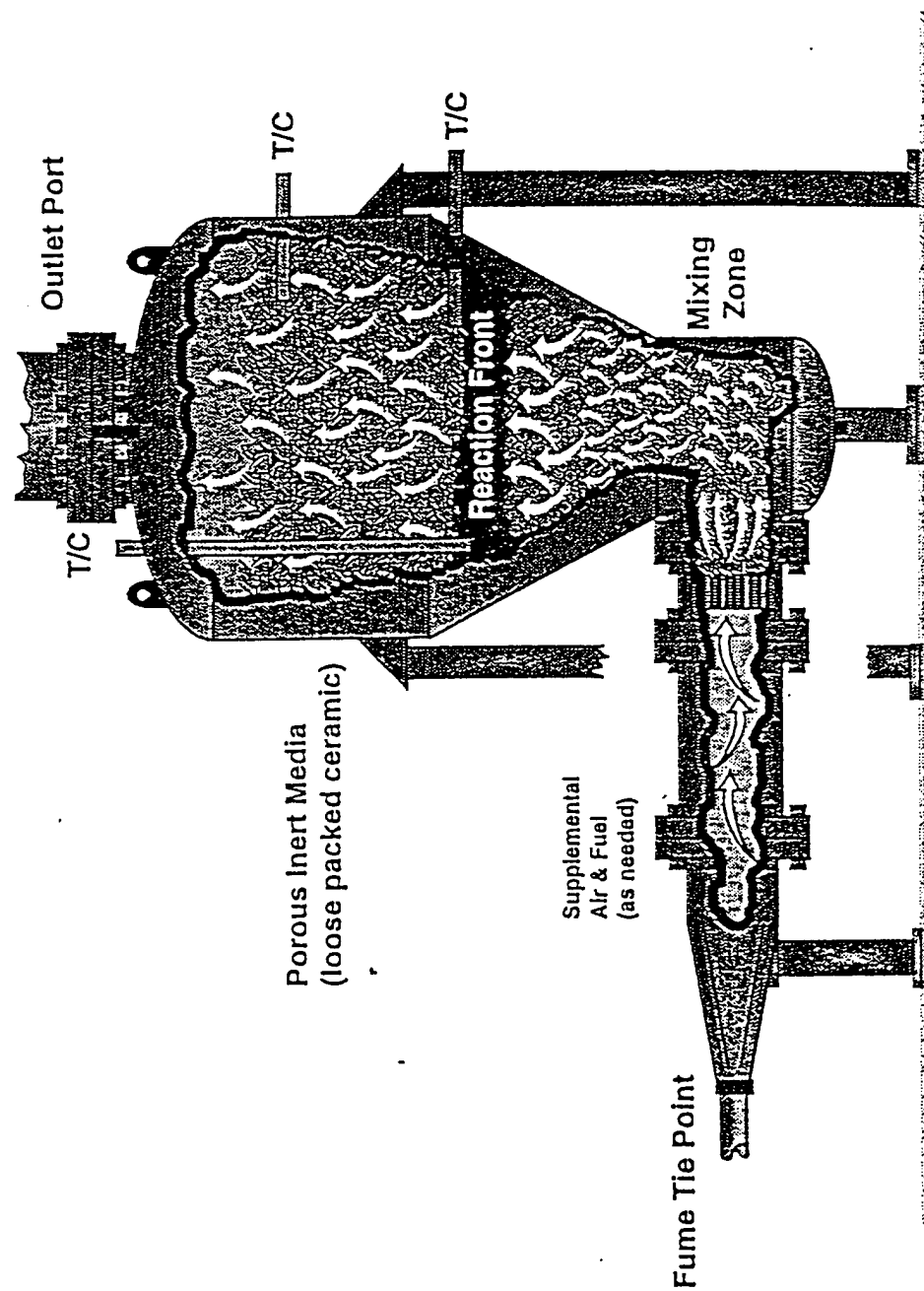


Figure 5
Cutaway Drawing of GS-3000M Reactor
Treatment of Pulp Mill Non-Condensable Gases

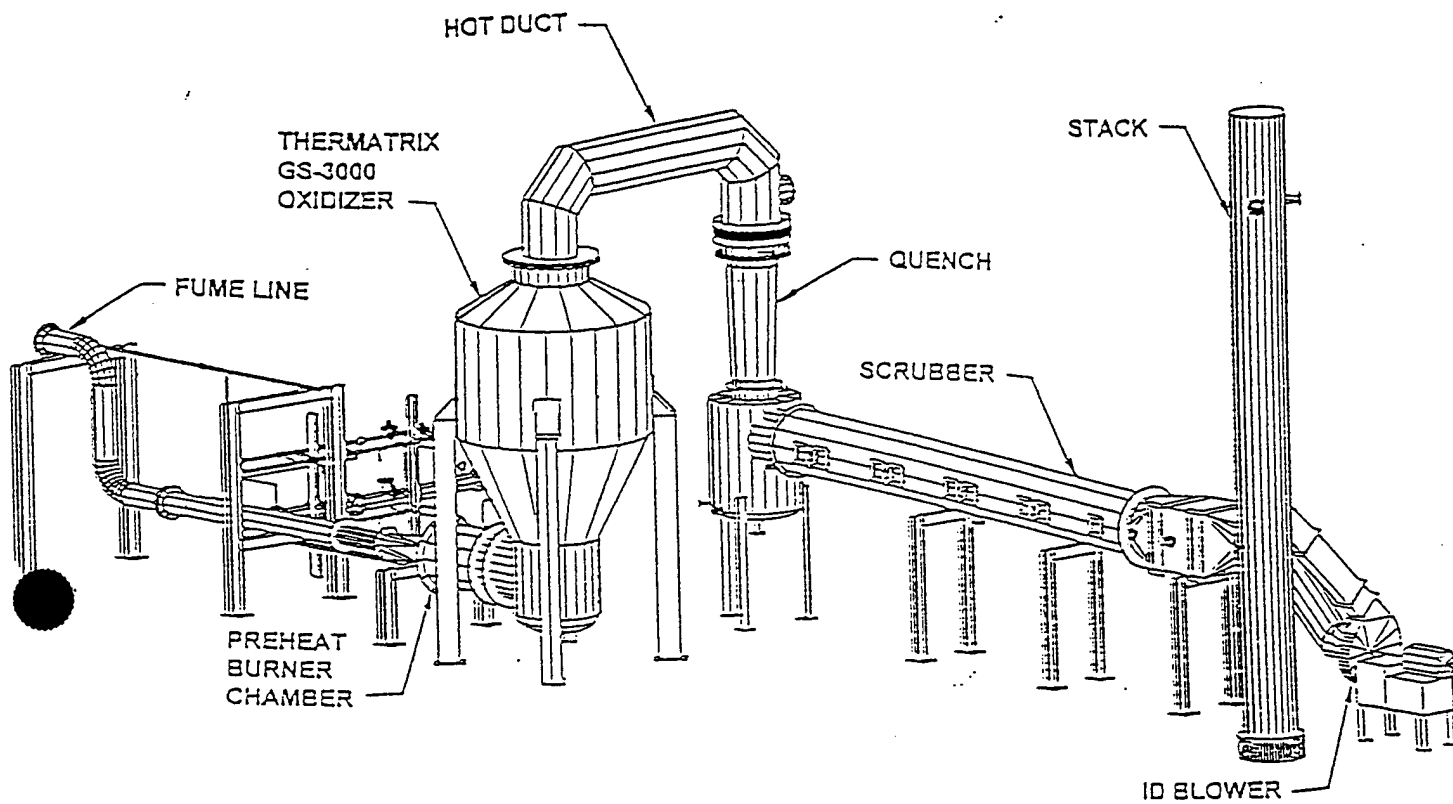


FIGURE 6

PULP PLANT NON-CONDENSABLE
GAS TREATMENT SYSTEM

U.S. Navy

Thermatrix has contracted with the Navy under its Navy Environmental Leadership to demonstrate the effectiveness of the thermal oxidation technology in treating VOC emissions from the fuel farm at the Naval Air Station North Island (NASNI). A 5 scfm electrically heated oxidizer has been fabricated for use in this demonstration. The demonstration will be performed in April 1995.

Department of Energy

The Thermatrix technology is applicable to the in-situ and ex-situ treatment of soils contaminated with organic compounds through coupling with other technologies, e.g., soil vapor extraction and thermal desorption.⁽³⁾ Thermatrix will demonstrate its thermal oxidation in the treatment of chlorinated VOCs removed from the vadose zone of the soil at the U. S. Department of Energy Savannah River Laboratory Site. A 5 scfm electrically heated unit will be used in this demonstration which couples soil vapor extraction technology with Thermatrix thermal oxidation technology. A schematic overview of planned demonstration is shown in Figure 7.

CONCLUSIONS

The successful application case histories presented above attest to the broad base of Thermatrix's thermal oxidation technology in providing solutions to organic compound treatment and site remediation. With over 30 projects completed to date, the Thermatrix thermal oxidation technology has rapidly transitioned from an innovative, emerging technology to full-scale application.

REFERENCES

1. R. J. MARTIN, et.al., "Selecting the Most Appropriate HAP Emission Control Technology," *The Air Pollution Consultant*, Volume 3, Issue 2 (March/April 1993).
2. M. W. ALLEN, et.al., "Flameless Thermal Oxidation for Low Concentration VOC Remedial Wastestreams: Designs for Planned DOE Demonstrations," presented at the Waste Management '95 Conference, February 26-March 2., 1995, Tucson, Arizona.
3. R. G. WILBOURN, et.al., "Treatment of Hazardous Wastes Using the Thermatrix Treatment System," presented at the 1994 Incineration Conference, May 9-13, 1994, Houston, Texas.

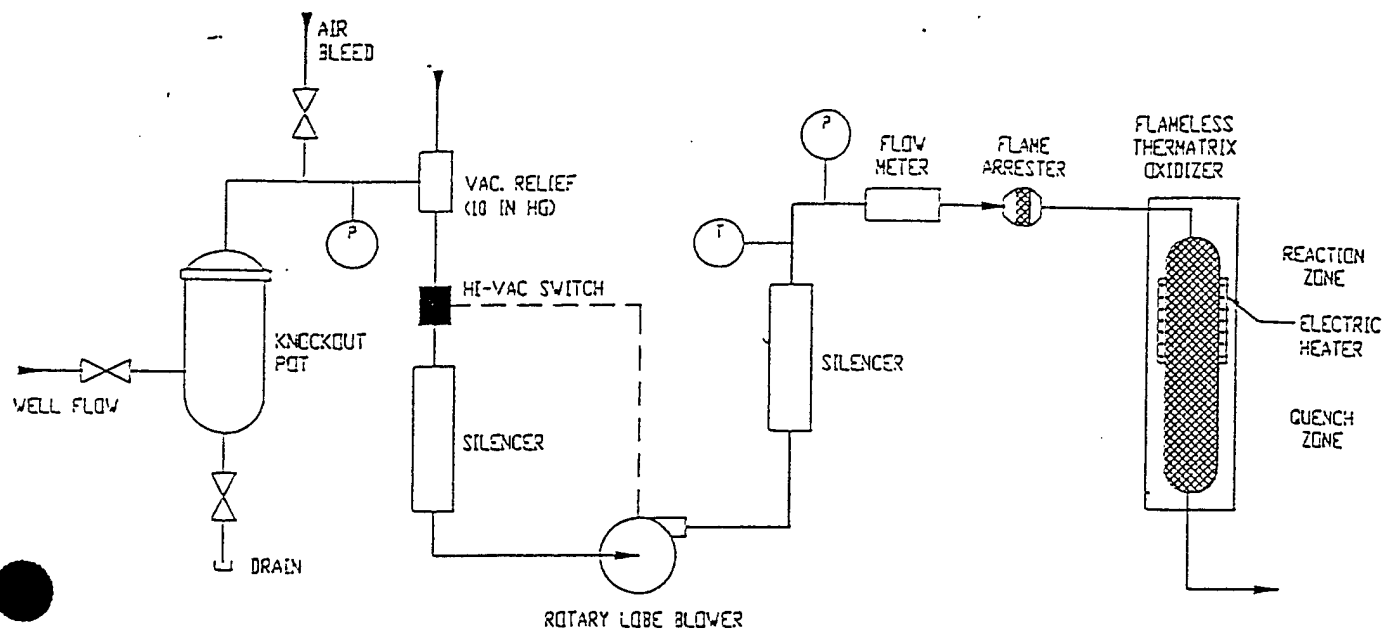


FIGURE 7

SCHEMATIC OVERVIEW OF THE SVE-THERMATRIX DEMONSTRATION

WESTINGHOUSE SAVANNAH RIVER DEMONSTRATION
INITIAL RESULTS

FTO Temp	FTO Flow	PCE inlet ppm	PCE outlet ppm	PCE %DRE	TCE inlet ppm	TCE outlet ppm	TCE %DRE	TCA inlet ppm	TCA outlet ppm	TCA %DRE	Comments
1600°F	5 scfm	737	<0.01	>99.998	292	<0.01	>99.996	17.5	<0.01	>99.94	1,1-DCE 5.56 in; <0.01 out
		702	<0.01	>99.998	274	<0.01	>99.996	21.4	<0.01	>99.95	
1600°F	7 scfm	568	0.17	99.97	255	<0.01	>99.996	16	<0.01	>99.95	1,1-DCE 4.72 in; <0.01 out
1500°F	5 scfm	345	4.43	98.7	184	<0.01	>99.994	16	<0.01	>99.95	
1700°F	5 scfm	343	0.01	99.997	180	<0.01	>99.994	15	<0.01	>99.93	1,1-DCE 4.09 in; <0.01 out; F113 0.03 in; <0.01 out
1400°F	5 scfm	333	0.51	99.84	179	<0.01	>99.994	12	<0.01	99.916	mono-, di-, tri-, tetra- chloro-methane PICS
1500°F	3.5 scfm	~350	<0.01	>99.997	~180	<0.01	>99.994	~15	<0.01	>99.93	
		~350	0.05	99.985	~180	<0.01	>99.994	~15	<0.01	>99.93	
1600°F	5 scfm	250	<0.001	>99.9996	120	<0.001	>99.9991	-----	-----	-----	4/25/95 Improved de- tection limit achieved

Notes:

- 1) Prior to the initial valving of fume through the oxidizer a "system blank" sample was taken while the pre-heated unit (1600°F) was operating on air flow only (5 scfm). No organics were detected at a detection limit of 10 ppb.
- 2) ">" values reflect quantitation limited by the analytical detection limit of 10 ppb for all compounds.
- 3) Results reported here are from sampling April 10-14, 1995 except for 4/25/95 entry.

APPENDIX B
FTO SYSTEM SAMPLING AND MONITORING INFORMATION

FTO TREATMENT SYSTEM SAMPLING AND MONITORING SCHEDULE
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Elapsed time, Frequency	Laboratory Samples ^{a/}		Field Measurements					
	Influent Soil Gas	Post- Treatment Effluent	Soil Gas O ₂ /CO ₂ /TVH ^{b/}	Thermatrix Oxidizer Influent ^{c/} VOCs	System Effluent VOCs	System Flow Rates and Pressures Measurements ^{d/}	EW Vacuum/Pressure Response	System Operation ^{e/}
Startup/Optimization								
0 Hour			X				X	
1 Hour	X	X	X	X	X	X		
Hourly; first 8 hours			X	X	X	X		
1 Day	X	X						
Daily; first week			X	X	X	X	X	
3 Days	X	X						
1 Week (7 days)	X	X	X	X	X	X	X	
Extended Testing								
Daily								X
Approximately every 14 days	X	X	X	X	X	X	X	

^{a/} Laboratory air sample analysis for volatile organic compounds (VOCs) using USEPA Method TO-14 (see Table 4.1).

^{b/} Soil gas oxygen, carbon dioxide, and total volatile hydrocarbons will be measured in both the extracted soil gas and at selected monitoring points.

^{c/} If extracted soil gas is diluted with fresh air prior to treatment, two field measurement samples will be collected, one before and one after dilution.

^{d/} Measurements will include extraction flow rate in standard cubic feet per minute, system operating pressures (inches of water), makeup water consumption (gpm), and supplemental fuel usage (propane in cubic feet).

^{e/} Daily system operation checks to be performed by site personnel during extended testing will include system operating (on/off), draining condensate knockout drum (if necessary), and notifying appropriate personnel during system shut-down.

TARGET VOLATILE ORGANIC COMPOUNDS^{a/}
FTO TREATMENT SYSTEM DEMONSTRATION
COMPREHENSIVE TECHNICAL REPORT

Freon-12	1,3,5-Trimethylbenzene
Freon-114	1,2,4-Trimethylbenzene
Chloromethane	1,3-Dichlorobenzene
Vinyl Chloride	1,4-Dichlorobenzene
Bromomethane	Chlorotoluene
Chloroethane	1,2-Dichlorobenzene
Freon 11	1,2,4-Trichlorobenzene
1,1-Dichloroethene	Hexachlorobutadiene
Freon 113	Propylene
Methylene Chloride	1,3-Butadiene
1,1-Dichloroethane	Acetone
cis-1,2-Dichloroethene	Carbon Disulfide
Chloroform	2-Propanol
1,1,1-Trichloroethane	trans-1,2-Dichloroethene
Carbon Tetrachloride	Vinyl Acetate
Benzene	Chloroprene
1,2-Dichloroethane	2-Butanone (Methyl Ethyl Ketone)
Trichloroethene	Hexane
1,2-Dichloropropane	Tetrahydrofuran
cis-1,3-Dichloropropene	Cyclohexane
Toluene	1,4-Dioxane
trans-1,3-Dichloropropene	Bromodichloromethane
1,1,2-Trichloroethane	4-Methyl-2-pentanone
Tetrachloroethene	2-Hexanone
Ethylene Dibromide	Dibromochloromethane
Chlorobenzene	Bromoform
Ethylbenzene	4-Ethyltoluene
m,p-Xylene	Ethanol
o-Xylene	Methyl t-Butyl Ether (MTBE)
Styrene	Heptane
1,1,2,2-Tetrachloroethane	

^{a/} USEPA Method TO-14, Air Toxics LTD., Folsom, CA.

March 13, 1997

Mr. Chuck Wright
Thermatrix, Inc.
308 N. Peters Road, Suite 225
Knoxville, Tennessee 37922

Subject: Air Force Contract No. F41624-94-D-8136, Delivery Order 28
Air Conformity Determination of Flameless Thermal Oxidation and
Internal Combustion Engine for VOC Off-Gas Abatement
Thermatrix Sampling Procedure Recommendations for Air Force Unit at
Plattsburgh, New York

Dear Mr. Wright:

The purpose of this letter is to provide a response to Mr. Marshall Allen's (Thermatrix, Inc.) memorandum dated February 21, 1997, and Mr. Rick Martin's (Thermatrix, Inc.) memorandum received via facsimile on March 4, 1997, regarding the sampling procedures used by Parsons Engineering Science, Inc. (Parsons ES) to evaluate the performance of the Thermatrix flameless thermal oxidizer (FTO) treatment unit operating at Plattsburgh, New York. Parsons ES agrees that analytical data reported in Analytical Data Reports 1 through 5 cannot be used to accurately determine the destruction removal efficiency (DRE) of the FTO treatment unit because inlet vapor samples were not collected following the addition of dilution air. Parsons ES will be collecting these inlet samples during the next 4 weeks of FTO treatment unit operation following the procedures provided below:

Influent Sampling

The influent vapor stream to the oxidizer will be sampled as follows:

Location: Influent to the oxidizer, exhaust side of the blower, combined vapor stream location.

Procedure: Using a new Tedlar® bag, connect the bag with a new short piece of Tygon® tubing to the combined sampling port. Open the valve on the sampling port to allow the Tedlar® bag to fill. Fill and evacuate the bag three times prior to collecting a sample. Once the Tedlar® bag is purged three times, fill the bag a final time, and collect a sample. Following sample collection, close both the Tedlar® bag and sampling port valve, before removing the bag from the sampling port.

Preparing the SUMMA® canister will consist of testing its vacuum both prior to (initial) and following sample collection. Once the initial vacuum is checked, the filled Tedlar® bag will be connected to a 1-liter SUMMA® canister. The bag valve will be opened, and then the SUMMA® canister valve will be opened slowly to allow the Tedlar® bag sample to enter the SUMMA® canister. Once the canister is full, the valve will be closed, and the SUMMA® canister will be prepared for shipment. SUMMA® canister filters will not be needed during influent sampling.

Effluent Sampling

The effluent vapor stream to the oxidizer will be sampled as follows:

Location: Oxidizer effluent within the center of stack opening approximately 6 inches below the top of the stack.

Procedure: Place the copper tubing into the stack so that one end is approximately 6 inches below the top of the stack and located in the center of the stack annulus. Connect a 1-cfm sampling pump to the other end of the copper tubing via Tygon® tubing to purge the tubing. An inline "tee" is placed approximately 3 feet from the top of the oxidizer exhaust within the copper tubing from which the SUMMA® canister sample will be collected. After purging the sample tube for at least 15 to 30 seconds, and continuing to purge using the 1-cfm pump, the SUMMA® canister sample will be collected through the inline "tee" via a short piece of dedicated rigid copper tubing fitted with the appropriated adapters in order to attach the SUMMA® canister. At this sample collection point a new, laboratory-supplied, prefilter will be attached to the canister inlet to prevent any particulates or moisture from entering the canister. Once the canister is completely evacuated, the valve will be closed, and the canister will be prepared for shipment.

Quality Control Sampling

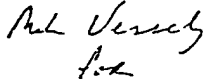
Prior to the first sampling event, a quality control (QC) effluent sample will be collected from the copper sampling tube. The QC sample will be collected in the field next to the system and would be considered a combination field and equipment blank. This SUMMA® canister sample will identify whether the tubing or ambient air could be contributing to any VOC detections in the effluent sample. The copper tubing will be purged a minimum of 15 seconds with ambient air using the 1-cfm pump prior to sample collection.

Mr. Chuck Wright
March 13, 1997
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Parsons ES appreciates Thermatrix, Inc.'s comments and time that Marshall Allen and Rick Martin have taken to discuss the sampling procedures with Steve Archabal (Parsons ES, Site Manager).

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.



Peter R. Guest, P.E.
Project Manager

cc: Marshall Allen, Thermatrix, Inc.
Rick Martin, Thermatrix, Inc.
Jim Gonzales, AFCEE/ERT
Mr. Brady Baker, AFBCA/OL3A
Mr. Ken Kukkonen, OHM
Mr. Rich Jasaitis, OHM
Doug Downey, Parsons ES-Denver
Steve Archabal, Parsons ES-Phoenix
Dave Brown, Parsons ES-Syracuse
File 728414

Thermatrix Memorandum

To: S. DeCicco, R. Martin, J. Newburn

From: C. Baer

Date: October 31, 1996

cc: F. van Breedam, R. Westbrook, K. Swayne, J. Dasch

Subject: Reduced inlet oxygen testing at Plattsburgh, NY using the Air Force unit

The Air Force unit, project 3780, is a GSC-40 with quench and scrubber that operates in Plattsburgh, NY destroying vapors from VOC and CVOC contaminated soil. The unit is currently configured as a gas straight through with the quench and scrubber bypassed due to the low concentration of chlorinated compounds. The soil vapor is oxygen depleted and offers an excellent opportunity to test the oxidizer at reduced oxygen conditions. Our goal is to determine the best combination of inlet oxygen concentration and fuel usage. A secondary goal of operating in the oxygen deficient or fuel rich zone was pursued.

During the week of October 14, 1996, the GS-40 oxidizer was tested with inlet oxygen concentrations varying from 7 to 14 percent. Our safe operating condition with this unit has been at 14 percent inlet oxygen which supplies excess oxygen to the unit for complete destruction and allows for minor variations in fume composition. The unit operates unmanned, except during changes in well locations. Prior to testing, the unit was operating at 100 scfm with the propane flow at 1.0 scfm with 14 percent inlet oxygen. TE-305 is our temperature control element located at the top of the cone with TE-306 located in the top cylinder 16 inches above TE-305. Our control temperature setpoint was 1100 F for the test. The propane flow is controlled by TE-305.

The oxygen concentration was lowered by increasing the fume flow and decreasing the dilution air flow to meet our specified inlet oxygen target with a constant total flow of 100 scfm. Preliminary reviews show the fuel usage trended lower with lower inlet oxygen concentrations during the test. We did not monitor the oxidizer outlet for VOC/CVOC concentrations and cannot comment on any changes in destruction efficiency. At lower oxygen concentrations (10 percent) TE-306 approached 2100 F which is our shutdown temperature. Therefore, the lowest oxygen concentrations could be attempted for only relatively short time periods (1-2 hours). Our results indicate the unit can operate efficiently at 11 percent inlet oxygen.

Sub-stoichiometric(fuel rich) testing was attempted at the end of the week. To accomplish this the oxygen concentration was lowered to 9 percent and the fuel flow was increased to 2.6 scfm. TE-305 stabilized at this condition. Increasing the propane flow to 2.7 scfm dropped the temperature at TE-305, and upon decreasing the propane flow to 2.5 scfm, TE-305 rose. During the test, the temperature at TE-306 rose above 2050 F at which point the test was discontinued. A detailed report on the test conditions will be completed in 4 weeks.

Thermatrix Memo

10/31/96

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My recommendation to Parsons is to lower the minimum inlet oxygen concentration from 14 to 12 percent in order for stable operation and fuel efficiency. The unit can operate lower than 12 percent, but this will give them some buffer if the well (furnace) oxygen concentration unexpectedly drops.

APPENDIX C
SITE ANALYTICAL DATA TABLES

SITE FT-002, PLATTSBURGH AIR FORCE BASE, NEW YORK

TABLE 1
DETECTED ANALYTES IN EXTRACTED VAPOR STREAM SAMPLES
MARCH 1997
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-002
PLATTSBURGH AIR FORCE BASE, NEW YORK

Analyte	Detected Concentration (ppbv) ^a						
	Influent Sample FT002VW6&14C1 3/5/97	Effluent Sample FT002VW6&14EN1 3/5/97	Destruction Efficiency (percent)	Ambient Sample FT002BLANK-1 3/6/97	Influent Sample FT002VW6&14C2 3/6/97	Effluent Sample FT002VW6&14EN2 3/6/97	Destruction Efficiency (percent)
1,2,4-Trimethylbenzene	6800	ND ^b	100	760	11000	ND	100.00
1,2-Dichlorobenzene	ND	ND	NA	14	ND	ND	NA
1,3,5-Trimethylbenzene	4100	ND	100	390	6700	ND	100.00
1,4-Dichlorobenzene	ND	ND	NA	5	ND	ND	NA
4-Ethyltoluene	5800	ND	100	520	9000	ND	100.00
Benzene	3700	ND	100	12	5200	5	99.90
cis-1,2-Dichloroethene	60000	ND	100	140	80000	55	99.93
Ethyl Benzene	920	ND	100	36	1400	ND	100.00
Freon 113	ND	ND	NA	ND	ND	ND	NA
Heptane	58000	ND	100	90	85000	60	99.93
Hexane	50000	ND	100	22	70000	21	99.97
m,p-Xylene	24000	ND	100	1100	35000	33	99.91
o-Xylene	14000	ND	100	790	21000	20	99.90
Tetrachloroethene	ND	ND	NA	ND	ND	ND	NA
Toluene	21000	ND	100	300	29000	38	99.87
Trichloroethene	12000	ND	100	73	16000	19	99.88
THC ^d	1500000	ND	100	12000	1700000	860	99.95

TABLE 1 (Continued)
DETECTED ANALYTES IN EXTRACTED VAPOR STREAM SAMPLES
MARCH 1997
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-002
PLATTSBURGH AIR FORCE BASE, NEW YORK

Analyte	Detected Concentration (ppbv)						Destruction Efficiency (percent)		Influent Sample FT002VW6C2 3/18/97		Effluent Sample FT002VW6EN2 3/18/97		Destruction Efficiency (percent)
	Influent Sample FT002VW6&14C2 DUP 3/6/97	Effluent Sample FT002VW6&14EN2-DUP 3/6/97	Destruction Efficiency (percent)	Influent Sample FT002VW6C1 3/11/97	Effluent Sample FT002VW6EN1 3/11/97	Destruction Efficiency (percent)							
1,2,4-Trimethylbenzene	9900	280	97.17	11000	7	99.94	5900	ND	ND	100.00	ND	ND	100.00
1,2-Dichlorobenzene	ND	ND	NA	ND	ND	NA	ND	ND	ND	NA	ND	ND	NA
1,3,5-Trimethylbenzene	6300	160	97.46	7600	5	99.93	4600	ND	ND	100.00	ND	ND	100.00
1,4-Dichlorobenzene	ND	ND	NA	ND	ND	NA	ND	ND	ND	NA	ND	ND	NA
4-Ethyltoluene	8300	220	97.35	9300	ND	100.00	9000	ND	ND	100.00	ND	ND	100.00
Benzene	ND	8	NA	5000	ND	100.00	7100	ND	ND	100.00	ND	ND	100.00
cis-1,2-Dichloroethene	83000	98	99.88	80000	7	99.99	120000	ND	ND	100.00	ND	ND	100.00
Ethyl Benzene	1300	19	98.54	1500	ND	100.00	1700	ND	ND	100.00	ND	ND	100.00
Freon 113	ND	ND	NA	ND	ND	NA	ND	ND	ND	NA	ND	ND	NA
Heptane	82000	75	99.91	94000	ND	100.00	99000	ND	ND	100.00	ND	ND	100.00
Hexane	72000	ND	100.00	80000	ND	100.00	82000	ND	ND	100.00	ND	ND	100.00
m,p-Xylene	33000	540	98.36	40000	14	99.97	38000	ND	ND	100.00	ND	ND	100.00
o-Xylene	20000	380	98.10	24000	9	99.96	19000	ND	ND	100.00	ND	ND	100.00
Tetrachloroethene	ND	ND	NA	ND	ND	NA	ND	ND	ND	NA	ND	ND	NA
Toluene	29000	180	99.38	30000	6	99.98	35000	ND	ND	100.00	ND	ND	100.00
Trichloroethene	16000	45	99.72	15000	4	99.97	22000	ND	ND	100.00	ND	ND	100.00
THC	2400000	5000	99.79	2300000	1400	99.94	2600000	ND	ND	100.00	ND	ND	100.00

TABLE 1 (Continued)
DETECTED ANALYTES IN EXTRACTED VAPOR STREAM SAMPLES
MARCH 1997
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-002
PLATTSBURGH AIR FORCE BASE, NEW YORK

Analyte	Detected Concentration (ppbv)						Destruction Efficiency (percent)		Influent Sample 3/25/97		Effluent Sample 3/23/97		Destruction Efficiency (percent)
	Influent Sample FT002VW14C1 3/19/97	Influent Sample FT002VW14C1 DUP 3/19/97	Effluent Sample FT002VW14EN1 3/19/97	Destruction Efficiency (percent)	Influent Sample FT002VW14C2 3/20/97	Effluent Sample FT002VW14EN2 3/20/97							
1,2,4-Trimethylbenzene	760	810	7	99.08	220	ND	100.00	100.00	ND	ND	ND	ND	NA ^d
1,2-Dichlorobenzene	ND	ND	ND	NA	ND	ND	NA	NA	ND	ND	ND	ND	NA
1,3,5-Trimethylbenzene	460	560	ND	100.00	150	ND	100.00	100.00	ND	ND	ND	ND	NA
1,4-Dichlorobenzene	ND	ND	ND	NA	ND	ND	NA	NA	ND	ND	ND	ND	NA
4-Ethyltoluene	700	780	ND	100.00	ND	ND	NA	NA	ND	ND	ND	ND	NA
Benzene	ND	ND	9	NA	ND	ND	NA	NA	ND	ND	ND	ND	NA
cis-1,2-Dichloroethene	1700	1600	ND	100.00	1600	ND	100.00	100.00	1900	ND	ND	ND	100.00
Ethyl Benzene	ND	ND	16	NA	160	ND	100.00	100.00	ND	ND	ND	ND	NA
Freon 113	180	140	ND	100.00	140	ND	100.00	100.00	99	ND	ND	ND	100.00
Heptane	2500	2900	31	98.76	2200	ND	100.00	100.00	ND	ND	ND	ND	NA
Hexane	ND	ND	ND	NA	ND	ND	NA	NA	ND	ND	ND	ND	NA
m,p-Xylene	1100	1000	22	98.00	460	ND	100.00	100.00	ND	ND	ND	ND	NA
o-Xylene	650	710	8	98.77	230	ND	100.00	100.00	200	ND	ND	ND	100.00
Tetrachloroethene	220	180	ND	100.00	240	ND	100.00	100.00	320	ND	ND	ND	100.00
Toluene	300	340	38	87.33	280	ND	100.00	100.00	ND	ND	ND	ND	NA
Trichloroethene	31000	31000	ND	100.00	24000	ND	100.00	100.00	19000	ND	ND	ND	100.00
THC	170000	130000	240	99.86	83000	ND	100.00	100.00	98000	ND	ND	ND	100.00

^a ppbv = parts per billion by volume, as determined by Air Toxics, Folsom, CA using USEPA

Method TO-14 GC/MS Full Scan. See Table 3 for field measurements and system operating conditions at the time of sampling.

^d ND = Not detected.

^e NA = Not applicable.

^f THC = Total hydrocarbons referenced to heptane (molecular weight = 100).

TABLE 2 (Revised)
FIELD MEASUREMENTS
FOR THERMAMATRIX SAMPLING EVENTS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-#2
PLATTSBURGH AIR FORCE BASE, NEW YORK

Well ID	Event Date and Time	Sample Date	Sample Time	Time Since Last Sample (hours)	Extraction Time (days)	Total Extraction Time (hours)	Blower Air Temperature (°F)	Flow Rate From Well (scfm)	Flow Rate Of Dilution Air (scfm)	Flow Rate Into Oxidizer (scfm)	TVH Before Dilution (ppm)	Oxygen Before Dilution (percent)	CO2 Before Dilution (percent)	TVH After Dilution (ppm)	Oxygen After Dilution (percent)	CO2 After Dilution (percent)	Comments
Run Mode	7/27/96, 2005																
VEW/VVW-6	8/28/96, 1200																Opened VEW/VVW-6
VEW/VVW-6	8/29/96, 1200																Closed VEW/VVW-6
Total Extraction Time - VEW/VVW-6					1	24											
MW-108	8/29/96, 1200																Opened MW-108
MW-108	9/2/96	15:30		NA	3.15	76	154	67.6	32.4	100		18.9					Blowdown Plot Test
MW-108	9/06/96, 1200				7.00	168											Closed MW-108
Total Extraction Time - MW-108					7	168											
VEW/VVW-6	9/06/96, 1200																Opened VEW/VVW-6
VEW/VVW-6	9/07/96, 1200				1	24											Estimated System Shutdown Time/Dates System shutdown was initiated on Sept 9 due to moisture in variable frequency drive, sample not collected
VEW/VVW-6	9/9/96																
Total Extraction Time - VEW/VVW-6					1.9	24											
Run Mode	9/18/96, 2120																
VEW/VVW-5	9/19/96, 1300																Opened VEW/VVW-5
VEW/VVW-5	9/25/96	1435		NA	6.1	145.5		43.5	56.5	100	2400	10	7.9	1950	16.2	7.9	sample collected
VEW/VVW-5	9/28/96, 1200				9.0	215.0											Estimated Shutdown time/date
VEW/VVW-5	9/30/96																Shutdown identified Sept 30 - electrical failure
Run Mode	10/1/96 1825																
VEW/VVW-5	10/2/96, 0900																System connected to well VEW/VVW-5 and operational at 0900 hours
VEW/VVW-5	10/3/96, 1200				1.13	27											Estimated Shutdown time/date
VEW/VVW-5	10/3/96																System shutdown identified Oct 3 due to electrical failure
Run Mode	10/4/96, 1851																
VEW/VVW-5	10/5/96, 1050																System connected to well VEW/VVW-5 and operational at 1000 hours
VEW/VVW-5	10/7/96, 1200				2.13	51											Estimated Shutdown time/date, accidental shutdown by electrician
Run Mode	10/9/96, 1700																
VEW/VVW-5	10/10/96																System shut down sometime prior to 10/9/96
VEW/VVW-5	10/10/96, 0915																System connected to VEW/VVW-5 at 0915
VEW/VVW-5	10/14/96, 1430			96	4.21	101											Closed VEW/VVW-5
Total Extraction Time - VEW/VVW-5					16.4	394											
Continuous Run																	
VEW/VVW-6	10/14/96, 1500																Opened VEW/VVW-6
VEW/VVW-6	10/14/96	1535		NA	0.02	0.58	120	19.1	80.9	100	6800	0	15	1300	14.5	4.9	Sample Collected
VEW/VVW-6	10/15/96	845		17.17	0.7	17.75	120	17.3	82.7	100	10400	0	21.5	1800	14.2	5.5	Sample Collected
VEW/VVW-6	10/16/96	1430		29.75	1.2	47.50	120	56.7	41.3	100	6350	0	16	3600	9.5	8	Sample Collected

TABLE 2 (Revised)
FIELD MEASUREMENTS
FOR THERMAMATRIX SAMPLING EVENTS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-402
PLATTSBURGH AIR FORCE BASE, NEW YORK

Well ID	Event Date and Time	Sample Date	Sample Time	Time Since Last Sample (hours)	Extraction Time (days)	Total Extraction Time (hours)	Blower Air Temperature (°F)	Flow Rate From Well (scfm)	Flow Rate Of Dilution Air (scfm)	Flow Into Oxidizer (scfm)	TVH Before Dilution (ppm)	Oxygen Before Dilution (percent)	CO2 Before Dilution (percent)	TVH After Dilution (ppm)	Oxygen After Dilution (percent)	CO2 After Dilution (percent)	Comments
VEW/VVW-6		10/18/96	1535	49.08	2.0	96.58	120	67.7	32.3	100	6200	6.6	9.4	4200	12.1	6.1	Sample Collected
VEW/VVW-6		10/24/96	945	138.17	5.8	234.75	120	56.5	43.5	100	6200	9	7.8	3500	14	5	Sample Collected
VEW/VVW-6	11/4/96, 1324			240.00	10.0	474.75					0						System shutdown due to high temp alarm.
Total Extraction Time - VEW/VVW-6																	
Run Mode	12/6/96, 0845																
VEW/VVW-7	12/6/96, 0845																
VEW/VVW-7		12/6/96	1010	NA	0.1	1.42	100	46.2	53.8	100	26	18	3	12	19.5	1.7	System on VEW/VVW-7 and operational at 0845
VEW/VVW-7		12/9/96	1115	73.08	3.0	74.50	100	76.9	23.1	100	260	15.9	3.2	200	17.5	2	Sample Collected
VEW/VVW-7	12/9/96, 1200			0.75	0.03	75.25											Sample Collected
Total Extraction Time - VEW/VVW-7																	
Continuous Run						3.1	75.25										Closed VEW/VVW-9
VEW/VVW-14	12/9/96, 1212																
VEW/VVW-14		12/9/96	1340	NA	0.1	1.47	108	81.3	18.8	100	320	11	6.5	260	15.5	3.7	Opened VEW/VVW-14
VEW/VVW-14		12/13/96	1105	93.42	3.9	94.89	108	64.3	35.7	100	420	16	4.1	270	18.7	2.2	Sample Collected
VEW/VVW-14	12/13/96, 1200			0.92	0.04	95.81											Sample Collected
Total Extraction Time - VEW/VVW-14																	
Continuous Run						4.0	95.81										Closed VEW/VVW-14
VEW/VVW-8	12/13/96, 1208																
VEW/VVW-8	12/16/96, 1612					73.07											Opened VEW/VVW-8
VEW/VVW-8	12/17/96, 1430																System Shutdown
VEW/VVW-8	12/18/96	1130	NA	3.9	3.9	94.07	117	44.8	55.2	100	580	13.5	4.7	260	16.5	2.9	System Restart
VEW/VVW-8	12/21/96, 1225					165.08											Sample Collected
VEW/VVW-8	12/24/96, 0820																Closed VEW/VVW-8 to remove ice blockage
VEW/VVW-8	12/24/96, 1000		930	72.18	3.0	166.25	110	53.6	46.4	100	970	NR	NR	520	NR	NR	Opened VEW/VVW-8
VEW/VVW-8						166.75											Sample collected, had O ₂ /CO ₂ meter
VEW/VVW-8	12/27/96	1330	75.00	0.50	0.02	242.25	101	60.0	40.0	100	850	NR	NR	510	NR	NR	Closed VEW/VVW-8 to switch to manifold from 1000 to 1100
VEW/VVW-8	12/27/96, 1400					242.25											Sample collected
Total Extraction Time - VEW/VVW-8																	
Continuous Run						10.1	242.25										Closed VEW/VVW-8
VEW/VVW-9	12/27/96, 1500						DEC	21.5									
VEW/VVW-9		12/27/96	1530	0.50	0.02	0.50	101	70.4	29.6	100	135	NR	NR	95	NR	NR	Opened VEW/VVW-9
VEW/VVW-9		1/3/97	1115	164.25	6.84	164.75	100	75.0	25.0	100	40	21	1	30	21	0.8	Sample collected
VEW/VVW-9	1/3/97, 1130			0.25	0.01	165.00											Sample collected
Total Extraction Time - VEW/VVW-9																	
Continuous Run						6.9	165.00										Closed VEW/VVW-9
VEW/VVW-12	1/3/97, 1150																
VEW/VVW-12		1/2/97	1555	4.08	0.17	4.08	103	69.2	30.8	100	260	15.8	4	180	17.7	2.8	Opened VEW/VVW-12
VEW/VVW-12	1/17/97, 0855			89.00	3.71	93.08											Sample collected
Total Extraction Time - VEW/VVW-12																	

TABLE 2 (Revised)
FIELD MEASUREMENTS
FOR THERMAL SAMPLING EVENTS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-002
PLATTSBURGH AIR FORCE BASE, NEW YORK

Well ID	Event Date and Time	Sample Date	Sample Time	Time Since Last Sample (hours)	Extraction Time (days)	Total Extraction Time (hours)	Blower Air Temperature (°F)	Flow Rate From Well (scfm)	Flow Rate Of Dilution Air (scfm)	Flow Rate Into Oxidizer (scfm)	TVH Before Dilution (ppm)	Oxygen Before Dilution (percent)	CO2 Before Dilution (percent)	TVH After Dilution (ppm)	Oxygen After Dilution (percent)	CO2 After Dilution (percent)	Comments
Total Extraction Time - VEW/VW-12																	
Continuous Run					3.9	93.08											
VEW/VW-13	1/7/97, 1505																Opened VEW/VW-13
VEW/VW-13		1/7/97	1600	0.92	0.04	0.92	96	47.5	52.5	100	2000	9	8.3	950	15.8	4.5	Sample collected
VEW/VW-13		1/14/97	0950	160.91	6.70	161.83	108	45.2	54.8	100	930	18.8	2.8	420	19.7	1.3	Sample collected
VEW/VW-13	1/14/97, 1000			0.17	0.01	162.00											Closed VEW/VW-13
Total Extraction Time - VEW/VW-13																	
Continuous Run					6.8	162.00											
VEW/VW-10	1/14/97, 1020																Opened VEW/VW-10
VEW/VW-10		1/14/97	1503	4.72	0.20	4.72	113	71.0	29.0	100	1000	13	6.3	710	15.8	14.3	Sample collected
VEW/VW-10	1/17/97, 2130			77.45	3.23	82.17											System shutdown due to weather-related low propane pressure.
Total Extraction Time - VEW/VW-10																	
Continuous Run					3.4	82.17											
Run Mode	1/21/97, 1515																System operational, TIC-315 control setpoint changed to 1200deg F
	1/22/97, 0400			13.25	0.55												System shutdown at 0400 due to basewide power outage.
	1/22/97, 1634																System operational
VEW/VW-3	1/22/97, 1708																Opened VEW/VW-3
VEW/VW-3		1/22/97	1848	1.67	0.07	1.67	110	40.9	59.1	100	2200	3.3	12.1	900	14.5	4.8	Sample collected
VEW/VW-3	1/27/97, 0300				4.34	105.92											System shutdown due to weather-related low propane pressure.
Total Extraction Time - VEW/VW-3																	
Continuous Run					4.41	105.92											
Run Mode	1/27/97, 1600																System operational
VEW/VW-4	1/27/97, 1825																Opened VEW/VW-4
VEW/VW-4		1/27/97	2030	2.10	0.09	2.10	94	49.1	50.9	100	570	6.8	8.7	280	14.9	4.3	Sample collected
VEW/VW-4		2/3/97	1225	159.90	6.66	162.00	114	47.9	52.1	100	1200	7.7	8.7	575	14.5	4.7	Sample collected
VEW/VW-4	2/3/97, 1235					162.00											Closed VEW/VW-4
Total Extraction Time - VEW/VW-4																	
Continuous Run					6.75	162.00											
VEW/VW-2	2/3/97, 1305																Opened VEW/VW-2
VEW/VW-2		2/3/97	1507	2.03	0.08	2.03	114	82.4	17.6	100	170	17.5	3.7	140	18.7	2.5	Sample collected
VEW/VW-2		2/4/97	1301	21.90	0.91	24.00	109	80.4	19.6	100	230	18	3.5	185	19.3	2.3	Sample collected
VEW/VW-2	2/4/97, 1325					24.50											Closed VEW/VW-2
Total Extraction Time - VEW/VW-2																	
Continuous Run					1.02	24.50											
VEW/VW-11	2/5/97, 1350																Opened VEW/VW-11
VEW/VW-11		2/5/97	1452	1.03	0.04	1.03	109	75.0	25.0	100	160	19.7	2	120	20.3	1.3	Sample collected
VEW/VW-11		2/7/97	1117	44.40	1.85	45.43	110	75.0	25.0	100	160	20.2	1.7	120	20.7	0.8	Sample collected
VEW/VW-11	2/7/97, 1148			0.50	0.50	45.93											Closed VEW/VW-11
Total Extraction Time - VEW/VW-11																	
Continuous Run					1.91	45.93											

TABLE 2 (Revised)
FIELD MEASUREMENTS
FOR THERMATRIX SAMPLING EVENTS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-402
PLATTSBURGH AIR FORCE BASE, NEW YORK

Well ID	Event Date and Time	Sample Date	Sample Time	Time Since Last Sample (hours)	Extraction Time (days)	Total Extraction Time (hours)	Blower Air Temperature (°F)	Flow Rate From Well (scfm)	Flow Rate Of Dilution Air (scfm)	Flow Rate Into Oxidizer (scfm)	TVH Before Dilution (ppm)	Oxygen Before Dilution (percent)	CO2 Before Dilution (percent)	TVH After Dilution (ppm)	Oxygen After Dilution (percent)	CO2 After Dilution (percent)	Comments
Continuous Run																	
VEW/VVW-6&14	2/7/97, 1204																
VEW/VVW-6&14		2/7/97	1310	NA	0.05	1.10	110	63.3	36.7	100	1500	6.7	10.8	950	14.7	5.7	Opened VEW/VVW-6&14
VEW/VVW-6&14		2/19/97	0906	283.90	11.83	285.00	130	75.4	24.6	100	3050	9.9	7.8	2300	13.8	5.7	Sample Collected
VEW/VVW-6&14		2/21/97	1200	61.10	2.55	337.10	113	63.5	36.5	100	2600	11	7.2	1650	15.8	4.2	Sample Collected
VEW/VVW-6&14		2/24/97	0839	68.70	2.86	405.80	106	63.9	36.1	100	1800	11.1	7.2	1150	17	3.7	Sample Collected
VEW/VVW-6&14		3/5/97	1630	224.20	9.34	630.00	112	60.0	40.0	100	3500	12	6.5	2100	17.1	3.1	Sample Collected. QA/QC samples collected
VEW/VVW-6&14		3/6/97	1030	18.00	0.75	648.00	106	66.7	33.3	100	3900	11.8	6.5	2600	15.8	4	Sample Collected
VEW/VVW-6&14	3/6/97, 1245				0.09	650.25											Closed VEW/VVW-14
Total Extraction Time - VEW/VVW-6&14					27.09	650.25											
Continuous Run																	
VEW/VVW-6	3/6/97, 1300																
VEW/VVW-6		3/11/97	1530	122.50	5.10	122.50	118	66.7	33.3	100	4200	14	5.5	2800	16.8	3.3	Operating exclusively on VEW/VVW-6
VEW/VVW-6	3/12/97, 1521																Sample Collected
Run Mode	3/14/97, 2300																System Shutdown. Sample pump shorted out system.
VEW/VVW-6	3/14/97, 2347																
VEW/VVW-6		3/18/97	1625	112.50	4.69	235.00	146	89.7	10.3	100	3900	15.2	4.5	3500	16	4	System Reset, Operating on VEW/VVW-6
VEW/VVW-6	3/18/97, 1700					235.50											Sample Collected
Total Extraction Time - VEW/VVW-6					9.81	235.50											Closed VEW/VVW-6
Continuous Run																	
VEW/VVW-14	3/18/97, 1715																Opened VEW/VVW-14
VEW/VVW-14		3/19/97	1645	23.50	0.98	23.50	150	62.5	37.5	100	640	15.9	4	400	18	2.1	Sample Collected
VEW/VVW-14		3/20/97	1720	24.40	1.02	47.90	148	74.6	25.4	100	590	13.8	4.1	440	16.9	2.6	Sample Collected
VEW/VVW-14		3/25/97	1337	116.30	4.85	164.20	140	78.7	21.3	100	375	16.7	3.9	295	18.3	2.6	Sample Collected
VEW/VVW-14	3/25/97, 1420					165.00				0.0							Closed VEW/VVW-14, Final System Shutdown
Total Extraction Time - VEW/VVW-14					6.88	165.00											Summary:
																	Total days onsite 210 days, 156 days of operation
																	Including run mode time, 141 days of vapor extraction.
																	139 days of vapor extraction with vapor sampling results.

TABLE 3
HYDROCARBON MASS REMOVAL AND EMISSIONS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-002
PLATTSBURGH AIR FORCE BASE, NEW YORK

Date Sampled	Extraction Well	Days of Operation	Influent THC ^a Concentration		Flow Rate (scfm)	Effluent THC Concentration ^a		Pounds of THC Removed	Total Daily THC Emissions ^a (pounds/day)
			(ppmv) ^b	(µg/L) ^c		(ppmv)	(µg/L)		
9/2/96	VEW/VW-6	3.90	5,800	24,111	100	3	12	842	0.10
9/23/96	VEW/VW-5	6.13	3,600	14,966	100	18	75	822	0.67
10/14/96	VEW/VW-6	0.02	3,300	13,719	100	120	499	3	4.47
10/24/96	VEW/VW-6	10.00	6,000	24,943	100	91	378	2,236	3.39
12/6/96	VEW/VW-7	0.08	23	96	100	32	133	0	1.19
12/9/96	VEW/VW-7	3.13	68	283	100	NA ^d	NA	8	- ^e
12/9/96	VEW/VW-14	0.06	120	499	100	NA	NA	0	-
12/13/96	VEW/VW-14	3.96	200	831	100	4	15	30	0.14
12/18/96	VEW/VW-8	4.98	690	2,868	100	NA	NA	128	-
12/24/96	VEW/VW-8	0.04	690	2,868	100	9	38	1	0.34
12/27/96	VEW/VW-8	3.23	530	2,203	100	12	50	64	0.45
12/27/96	VEW/VW-9	0.02	20	83	100	NA	NA	0	-
1/3/97	VEW/VW-9	6.83	18	75	100	4	18	5	0.16
1/3/97	VEW/VW-12	0.19	180	748	100	5	21	1	0.19
1/7/97	VEW/VW-12	3.66	580	2,411	100	NA	NA	79	-
1/7/97	VEW/VW-13	0.04	490	2,037	100	26	108	1	0.97
1/14/97	VEW/VW-13	6.75	180	748	100	NA	NA	45	-
1/14/97	VEW/VW-10	0.20	550	2,286	100	NA	NA	4	-
1/22/97	VEW/VW-3	4.42	1,200	4,989	100	24	100	198	0.89
1/27/97	VEW/VW-4	0.08	ND	ND	100	ND	ND	0	-
2/3/97	VEW/VW-4	12.67	870	3,617	100	NA	NA	411	-
2/3/97	VEW/VW-2	0.08	12	50	100	3	13	0.04	0.12
2/4/97	VEW/VW-2	0.92	13	54	100	NA	NA	0.4	-
2/4/97	VEW/VW-11	0.08	25	104	100	4	17	0.1	0.16
2/7/97	VEW/VW-11	2.84	24	100	100	NA	NA	3	-
2/7/97	VEW/VW-6 and -14	0.40	1,500	6,236	100	32	133	22	1.19
2/19/97	VEW/VW-6 and -14	11.92	3,700	15,381	100	88	366	1,644	3.28
2/21/97	VEW/VW-6 and -14	1.88	3,800	15,797	100	140	582	266	5.22
2/24/97	VEW/VW-6 and -14	2.85	4,200	17,460	100	220	915	446	8.20
3/5/97	VEW/VW-6 and -14	9.34	1,500	6,236	100	0	0	522	0.00
3/6/97	VEW/VW-6 and -14	0.75	1,700	7,067	100	0.9	4	48	0.03
3/11/97	VEW/VW-6	0.10	2,300	9,561	100	1.4	6	9	0.05
3/18/97	VEW/VW-6	3.69	2,600	10,809	100	0	0	358	0.00
3/19/97	VEW/VW-14	0.98	170	707	100	0.2	1	6	0.01
3/20/97	VEW/VW-14	1.02	83	345	100	0	0	3	0.00
3/25/97	VEW/VW-14	4.85	98	407	100	0	0	18	0.00
Total =								8,221	

^a Values given are for total hydrocarbons (THC) referenced to heptane (molecular weight =100).

^b Effluent sample results from samples collected from 9/2/96 through 2/24/97 may be anomalously high due to the use of sampling procedures that may have caused cross-contamination of the sample. procedures that may have caused cross-contamination of the sample (see Attachment 1).

^c ppmv = parts per million by volume, as determined by the analytical laboratory.

^d µg/L = micrograms per liter, as determined by the analytical laboratory.

^e NA = not analyzed.

^f Effluent samples not collected during sampling event.

BUILDING 181, AIR FORCE PLANT 4, TEXAS

TABLE 1
FIELD MEASUREMENTS AND SYSTEM OPERATING CONDITIONS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
BUILDING 181
AIR FORCE PLANT 4, TEXAS

Extraction Wells	Date	Time	Run Time				Cumulative System				Possible Run Time (percent)	Dilution Valve Opening (percent)	Flow Rate Into Oxidizer (scfm)	Inlet Field VOC Concentration		Comments
			Run Time Meter (hours)	Since Last Event (hours)	Extraction Time (hours)	Down Time due to Unit Problems (hours)	Down Time due to External Problems (hours)	Down Time due to Cumulative System Problems (hours)	Down Time due to Cumulative System Problems (hours)	Down Time due to Cumulative System Problems (hours)				Pre-Dilution Concentration (ppmv)	Post-Dilution Concentration (ppmv)	
PZ-1, PZ-4, UZ-1	4/19/97	1600	0	0	0	0	0	0	0	0	0		115		560	
PZ-1, PZ-4, UZ-1	4/20/97	800	16	16	0	0	0	0	0	100	100		115		850	
All	4/20/97	930	1.5	17.5	0	0	0	0	0	100	100		105		340	
All	4/20/97	1400	4.5	22	0	0	0	0	0	100	100		105		305	
All	4/20/97	1815	4.25	26.25	0	0	0	0	0	100	100		105		305	
All	4/21/97	1650		26.25	21.25	0	0	0	0	55	55		105		293	Unit down due to loss of pH signal - 4/20/97, 18:15 - 4/21/97 16:50
All	4/22/97	900	3034.5	17	43.25	21.25	0	0	0	67	67	16.5	105		320	Unit restarted and in run mode on soil vapor
All	4/22/97	1545		6.75	50	21.25	0	0	0	70	70	24.2	105		245	Collected influent and effluent VOC samples
All	4/23/97	1200		20.25	70.25	21.25	0	0	0	77	77		105	280	205	Collected influent VOC and effluent VOC and HCL samples
All	4/24/97	1300		25	95.25	21.25	0	0	0	82	82		105	215	205	Unit auto shutdown due to loss of external water supply
All	4/25/97	0000		0	95.25	21.25	0	0	0	75	75		105			Unit restarted and in run mode on soil vapor
All	4/25/97	1600		16	111.25	21.25	0	0	0	78	78		105			Collected influent VOC and effluent VOC and HCL samples
All	5/8/97	1800	3423.6	312	423.25	21.25	11	11	11	93	93	40	105	303	287	Unit auto shutdown due to loss of external water supply
All	5/9/97	940	3439.3	15.7	438.95	21.25	11	11	11	94	94	0	105	230	123	Unit restarted and in run mode on soil vapor
All	5/12/97	1100	3513.9	74.6	513.55	21.25	11	11	11	94	94	0	105		233	Collected influent VOC and effluent VOC and HCL samples
All	5/19/97	1800	3520.8	0	513.55	21.25	11	11	11	71	71	0	105			Unit auto shutdown due to float switch stuck in water discharge tank (external)
All	5/20/97	0715	3533.5	12.7	526.25	21.25	11	11	11	71	71	0	105			Unit restarted and placed in run mode
All	5/20/97	1115	3537.5	4	530.25	21.25	11	11	11	71	71	0	105			
All	5/25/97 ^u	1200 ^u	3638.8	121.3	651.55	21.25	11	11	11	75	75		105			
All	6/2/97	1945	3665.9	0	651.55	21.25	11	11	11	61	61	12	105	102	36.1	Unit auto shutdown due to empty propane tank (external)
All	6/3/97	0815	3678.4	12.5	664.05	21.25	11	11	11	62	62	22.5	105	315	280	Unit restarted and placed in run mode
All	6/16/97	1050	3992.9	314.5	978.55	21.25	11	11	11	70	70	23.5	105	183	188	Collected influent and effluent VOC samples
All	6/17/97	800	4014.7	21.8	1000.35	21.25	11	11	11	71	71	23.3	105	279	277	Collected influent and effluent VOC samples
All	6/30/97	1130	4329.7	315	1293.55	21.25	11	11	11	76	76	24.5	105	394	349	
All	6/30/97	1430	4332.7	3	1296.55	21.25	11	11	11	76	76	24.6	105	313	305	
All	7/8/97 ^u	1612 ^u	4526.4	193.7	1490.25	21.25	11	11	11	78	78		105			Unit auto shut down due to low water level in quench tank. ^u
All	8/5/97	1630		0	1490.25	21.25	11	11	11	50	50		105			Unit restarted and placed in run mode
All	8/8/97	1500 ^u	4584	57.6	1547.85	21.25	11	11	11	51	51		105			Unit auto shutdown due to float switch stuck in water discharge tank (external)
All	8/17/97	1600	4590	0	1560.75	21.25	11	11	11	48	48		105		200	Unit restarted and placed in run mode
All	8/26/97	900 ^u		209	1699.25	21.25	11	11	11	50	50		105			Unit auto shutdown due to low flow to the scrubber because of fluctuations in water supply
All	9/10/97	1630		0	1699.25	21.25	11	11	11	45	45		105			Unit restarted and placed in run mode
All	10/15/97	1430		838	2537.25	21.25	11	11	11	55	55		105			Unit shut down by IT Corporation; FTO demonstration and sampling concluded

^u Approximate.

^u It was determined during the July 14, 1997 inspection that a thermocouple and water solenoid valve required replacement. However, the July 8, 1997 shutdown of FTO unit resulted from a loss of water supply to the scrubber system and did not result from the failure of these items.

TABLE 2
HYDROCARBON MASS REMOVAL AND EMISSIONS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
BUILDING 181
AIR FORCE PLANT 4, TEXAS

Date Sampled	Extraction Wells	Days of Operation	Influent TCE ^v		Flow Rate (scfm)	Pounds of TCE Removed	Effluent THC ^v		Total Daily THC Emissions ^v (pounds/day)	Effluent HCL Concentration (mg/L)	Total Daily HCL Emissions (pounds/hour)
			Concentration (ppmv) ^v	Concentration (µg/L) ^v			Concentration (ppmv)	Concentration (µg/L)			
4/22/97	PZ-1-PZ-7, and UZ-1	2.08	130	711	105	14	0.25	1.0	0.01	NA ^d	NA
4/23/97	PZ-1-PZ-7, and UZ-1	0.84	120	656	105	5	0.54	2.2	0.02	0.17	0.066
4/25/97	PZ-1-PZ-7, and UZ-1	1.71	140	765	105	12	0.00	0.0	0.00	ND ^e	0
5/8/97	PZ-1-PZ-7, and UZ-1	13.00	67	366	105	45	0.36	1.5	0.01	ND	0
6/3/97	PZ-1-PZ-7, and UZ-1	10.03	170	929	105	88	0.00	0.0	0.00	NA	NA
6/16/97	PZ-1-PZ-7, and UZ-1	13.10	110	601	105	74	0.55	2.3	0.02	NA	NA
6/30/97	PZ-1-PZ-7, and UZ-1	14.16	95	519	105	69	0.47	2.0	0.02	NA	NA
10/15/97 ^d	PZ-1-PZ-7, and UZ-1	51.68	95	519	105	253	0.47	2.0	0.02	NA	NA
Total = 106.61						Total = 560					

^a Values given for total hydrocarbons (THC) are referenced to heptane (molecular weight = 100), TCE molecular weight is 131.5.

Samples collected after addition of dilution air.

^b ppmv = parts per million by volume, as determined by the analytical laboratory.

^c µg/L = micrograms per liter, as determined by the analytical laboratory.

^d NA = not analyzed.

^e ND = not detected.

^f No samples were collected during the final shutdown of the FTO unit; therefore, the June 30, 1997 analytical data were used for this estimate. The days of operation between June 30, 1997 and October 15, 1997 was calculated for Table 1.

**SOURCE AREA REDUCTION SYSTEM,
FORMER LOWRY AIR FORCE BASE, COLORADO**

TABLE 2
FIELD MEASUREMENTS AND SYSTEM OPERATING CONDITIONS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
SOURCE AREA REDUCTION SYSTEM
FORMER LOWRY AIR FORCE BASE, COLORADO

Date ^a	Time	Possible Run		Run Time Meter	Run Time Event	Run Time Since Last	Cumulative Run Time ^b	Cumulative Down Time Due To Unit Problems	Cumulative Down Time Due To External Problems	Isolated Down Time	Flow Rate Into Oxidizer (scfm)	Fume Portion of Flow (percent)	Ambient Portion of Flow (percent)	Comments	
		Time (hours)	Time (hours)												
5/20/98	0800	0	0	NR ^d	0	0.0	0.0	0.0	0.0		105	75	25	Collected SARS-IK01-80, SARS-IOX1-105, and SARS-EOX1-105	
5/21/98	1017	26.2	26.2	5725.0	26.2	26.2	26.2	0.0	0.0						
5/22/98	1030	24.2	50.4	NR	24.2	50.4	50.4	0.0	0.0		105	75	25	Collected SARS-IOX2-105 and SARS-EOX2-105	
5/26/98	0200	87.5	137.9	5841.8	87.5	137.9	137.9	0.0	0.0					System down due to power outage	
5/28/98	0910	55.2	193.1	5841.8	0.0	137.9	0.0	0.0	55.2	55.2	105	75	25	System restart	
6/3/98	1622	151.3	344.4	5993.1	151.3	289.2	289.2	0.0	55.2	55.2				System down due to SARS shut-down resulting in low flow	
6/4/98	0712	14.8	359.2	5993.1	0.0	289.2	0.0	0.0	69.9	69.9	105	75	25	System restart	
6/4/98	2242	15.5	374.7	6008.6	15.5	304.7	304.7	0.0	69.9	69.9				System down due to high water level in moisture separator	
6/10/98	0655	128.2	502.9	6008.6	0.0	304.7	0.0	0.0	198.1	198.1	105	75	25	System restart	
6/18/98	0900	186.7	689.6	6195.3	186.7	491.4	491.4	0.0	198.1	198.1	105	75	25	Collected SARS-IOX3-105 and SARS-EOX3-105	
6/21/98	1813	275.3	778.2	6283.9	275.3	580.0	580.0	0.0	198.1	198.1				System down due to high water level in moisture separator	
6/23/98	1000	39.8	818	6283.9	0.0	580.0	0.0	0.0	238.0	238.0	105	75	25	System restart	
7/8/98	1700	367.1	1185.1	6651.0	367.1	947.1	947.1	0.0	238.0	238.0				System down due to power outage	
7/13/98	1225	115.5	1300.6	6651.0	0.0	947.1	0.0	0.0	353.5	353.5	105	75	25	System restart	
7/15/98	1025	46	1346.6	6697.0	46.0	993.1	993.1	0.0	353.5	353.5				System down due to power outage	
7/21/98	0900	142.6	1489.2	6697.0	0.0	993.1	0.0	0.0	496.1	496.1	105	75	25	System restart, Collected SARS-IOX4-105 and SARS-EOX4-105 and EB-1	
7/24/98	1930	82.5	1571.7	6779.5	82.5	1075.6	1075.6	0.0	496.1	496.1				System down due to power outage	
7/28/98	0800	84.5	1656.2	6779.5	0.0	1075.6	0.0	0.0	580.6	580.6	105	75	25	System restart	
7/30/98	0110	41.2	1697.4	6820.7	41.2	1116.8	1116.8	0.0	580.6	580.6				System down due to power outage	
8/3/98	0805	102.9	1800.3	6820.7	0.0	1116.8	0.0	0.0	683.5	683.5	105	75	25	System restart	
8/7/98	1017	98.2	1898.5	6918.9	98.2	1215.0	1215.0	0.0	683.5	683.5				System down due to power outage	
8/10/98	0935	71.3	1969.8	6918.9	0.0	1215.0	0.0	0.0	754.8	754.8	105	80	20	System restart, Collected SARS-IOX5-105 and SARS-EOX5-105	
8/10/98	1736	8.1	1977.9	6927.0	8.1	1223.1	1223.1	0.0	754.8	754.8				System down due to power outage	
8/12/98	0910	39.5	2017.4	6927.0	0.0	1223.1	0.0	0.0	794.3	794.3	105	75	25	System restart	
8/13/98	1316	28.1	2045.5	6955.1	28.1	1251.2	1251.2	0.0	794.3	794.3				System down due to power outage	
8/17/98	0914	68.0	2113.5	6955.1	0.0	1251.2	0.0	0.0	862.3	862.3	105	75	25	System restart	
8/19/98	0420	43.1	2156.6	6998.2	43.1	1294.3	1294.3	0.0	862.3	862.3				System down due to low flow FALL-206	
8/19/98	0938	5.3	2161.9	6998.2	0.0	1294.3	0.0	5.3	862.3	862.3	105	75	25	System restart	
8/19/98	2050	11.2	2173.1	7009.4 ^d	11.2	1305.5	1305.5	5.3	862.3	862.3				System down due to power outage	
8/24/98	0727	106.6	2279.7	0.0	0.0	1305.5	5.3	5.3	968.9	968.9	105	75	25	System restart	
8/24/98	1640	9.2	2288.9	9.2	9.2	1314.7	5.3	5.3	968.9	968.9				System down due to low flow FALL-206	
8/26/98	1619	47.7	2336.6	9.2	0.0	1314.7	53.0	53.0	968.9	968.9	105	75	25	System restart	
8/27/98	1006	17.8	2354.4	27.1	17.8	1332.5	53.0	53.0	968.9	968.9				Collected SARS-IOX6-105 and SARS-EOX6-105 and EB-2	
9/1/98	1413	124.1	2478.5	151.2	124.1	1456.6	53.0	53.0	968.9	968.9	105	75	25	FTO unit is shut down. Conclusion of FTO demonstration and sampling.	
Cumulative Operational Efficiency = 57%										98%					
Unit Problems Operational Efficiency = 57%										61%					
External Problems Operational Efficiency = 57%										61%					

^a Vapors from IRAEW-01 through IRAEW-15 are being treated.

^w Cumulative run time includes time during start-up (i.e., purge, preheat, cool bed, and profile modes).

^d NR = not recorded.

^w This hour meter reading corresponds with Advanced Security Technologies call to Parsons ES. The hour meter was broken.

TABLE 3
TOTAL HYDROCARBON MASS REMOVAL AND EMISSIONS
FLAMELESS THERMAL OXIDATION DEMONSTRATION
SOURCE AREA REDUCTION SYSTEM
FORMER LOWRY AIR FORCE BASE, COLORADO

Date Sampled	Extraction Wells	Days of Operation	Influent THC ^{a/}		Flow Rate (scfm)	Effluent THC		Pounds of THC Remove	Total Daily THC Emissions ^{b/} (pounds/day)
			Concentration (ppmv) ^{b/}	Concentration (µg/L) ^{c/}		Concentration (ppmv)	Concentration (µg/L)		
5/20/98	IRAEW 01-15	1.0	9.5	39	105	5.4	22	0.37	0.2
5/22/98	IRAEW 01-15	2.0	8.9	37	105	<0.05	< 0.22	0.70	0.0021
6/18/98	IRAEW 01-15	18.4	9.0	37	105	0.10	< 0.41	6.48	0.0039
7/21/98	IRAEW 01-15	21.0	8.5	35	105	<0.05	< 0.22	6.99	0.0021
8/10/98	IRAEW 01-15	10.0	3.0	12	105	<0.05	< 0.22	1.17	0.0021
8/27/98	IRAEW 01-15	4.5	10.0	41	105	<0.05	< 0.22	1.74	0.0021
Total =		56.9				Total =		17.4	

^{a/} Values given are for total hydrocarbons (THC) referenced to heptane (molecular weight = 100) after addition of dilution air.

^{b/} ppmv = parts per million by volume, as determined by the analytical laboratory.

^{c/} µg/L = micrograms per liter, as determined by the analytical laboratory.

TABLE 3
DETECTED ANALYTES IN EXTRACT
MAY TO AUG
FTO TREATMENT SYSTEM
SOURCE AREA REDUC
FORMER LOWRY AFB

Analyte	Pre-Dilution	Post Dilution			Post Dilution			Post Dilution			Detector
	Influent Sample SARS-IK01-80 5/20/98	Influent Sample SARS-IOX1-105 5/20/98	Effluent Sample SARS-EOX1-105 5/20/98	Destruction Efficiency (percent)	Influent Sample SARS-IOX2-105 5/22/98	Effluent Sample SARS-EOX2-105 5/22/98	Destruction Efficiency (percent)	Influent Sample SARS-IOX3-105 6/18/98	Effluent Sample SARS-EOX3-105 6/18/98	Destruction Efficiency (percent)	Ir S.
Freon 12	<53 ^b	<35	<5.4	NA ^c	<42	<5.3	NA	<25	<5.1	NA	
Vinyl chloride	120	100	<5.4	>99.99	100	<5.3	>99.99	96	<5.1	>99.99	
1,1-Dichloroethene	180	210	<5.4	>99.99	200	<5.3	>99.99	150	<5.1	>99.99	
Methylene chloride	130	110	<5.4	>99.99	100	<5.3	>99.99	66	<5.1	>99.99	
1,1-Dichloroethane	<53	<35	<5.4	NA	<42	<5.3	NA	<25	<5.1	NA	
cis-1,2-Dichloroethene	940	700	<5.4	>99.99	680	<5.3	>99.99	480	<5.1	>99.99	
1,1,1-Trichloroethane	860	650	<5.4	>99.99	650	<5.3	>99.99	650	<5.1	>99.99	
Tetrachloroethene	210	160	<5.4	>99.99	180	<5.3	>99.99	140	<5.1	>99.99	
Toluene	<53	<35	7.2	NA	<42	<5.3	NA	<25	<5.1	NA	
m,p-Xylenes	<53	<35	12	NA	<42	<5.3	NA	<25	<5.1	NA	
o-Xylene	<53	<35	6	NA	<42	<5.3	NA	<25	<5.1	NA	
1,2,4-Trimethylbenzene	<53	<35	6.1	NA	<42	<5.3	NA	<25	<5.1	NA	
Acetone	<210	<140	<22	NA	<170	<21	NA	<99	23	NA	
2-Butanone	300	<140	<22	NA	<170	<21	NA	<99	<20	NA	
Tetrahydrofuran	960	<140	38	NA	<170	<21	NA	<99	<20	NA	
Cyclohexane	<210	<140	23	NA	<170	<21	NA	<99	<20	NA	
1,4-Dioxane	<210	<140	24	NA	<170	<21	NA	<99	<20	NA	
Trichloroethene	9200	7000	<5.4	>99.99	6900	9.8	99.86	6200	<20	>99.99	
THC ^d	15000	9500	540	94.32	8900	<53	>99.99	9400	96	98.98	

^a ppbv = parts per billion by volume, as determined by Air Toxics, Folsom, CA using USEPA

Method TO-14 GC/MS Full Scan. See Table 3.4 for field measurements and system operating conditions at the time of sampling.

^b < = Compound not detected, value shown represents the reporting limit.

^c NA = Not applicable.

^d THC = Total hydrocarbon compounds referenced to heptane (molecular weight = 100).

TABLE 3.1
TRACTED VAPOR STREAM SAMPLES
O AUGUST 1998
SYSTEM DEMONSTRATION
A REDUCTION SYSTEM
WRY AFB, COLORADO

Detected Concentration (ppbv) ^a											
struction	Post Dilution			Effluent Sample Equipment Blank	Post Dilution			Effluent Sample Equipment Blank	Post Dilution		
	Influent Sample	Effluent Sample	Destruction		Influent Sample	Effluent Sample	Destruction		Influent Sample	Effluent Sample	Destruction
Efficiency	SARS-IOX4-105	SARS-EOX4-105	Efficiency	EB-1	SARS-IOX5-105	SARS-EOX5-105	Efficiency	EB-1	SARS-IOX6-105	SARS-EOX6-105	Efficiency
(percent)	7/21/98	7/21/98	(percent)	7/21/98	8/10/98	8/10/98	(percent)	8/27/98	8/27/98	8/27/98	(percent)
NA	<37	<5.4	NA	<5.1	<25	<5.3	NA	<21	<5.7	NA	28
99.99	100	<5.4	>99.99	<5.1	71	<5.3	>99.99	<4.9	180	<5.7	>99.99
99.99	260	<5.4	>99.99	<5.1	130	<5.3	>99.99	<4.9	180	<5.7	>99.99
99.99	100	<5.4	>99.99	6.3	120	<5.3	>99.99	<4.9	69	<5.7	>99.99
NA	47	<5.4	>99.99	<5.1	<25	<5.3	NA	<4.9	35	<5.7	>99.99
99.99	1500	<5.4	>99.99	<5.1	760	<5.3	>99.99	<4.9	960	<5.7	>99.99
99.99	930	<5.4	>99.99	<5.1	460	<5.3	>99.99	<4.9	540	<5.7	>99.99
99.99	280	10	96.43	11	180	<5.3	>99.99	<4.9	120	<5.7	>99.99
NA	<37	<5.4	NA	<5.1	<25	<5.3	NA	<4.9	<21	<5.7	NA
NA	<37	<5.4	NA	<5.1	<25	<5.3	NA	<4.9	<21	<5.7	NA
NA	<37	<5.4	NA	<5.1	<25	<5.3	NA	<4.9	<21	<5.7	NA
NA	<37	<5.4	NA	<5.1	<25	<5.3	NA	<4.9	<21	<5.7	NA
NA	<150	23	NA	<20	<100	<21	NA	<20	<84	<23	NA
NA	<150	<22	NA	<20	<100	<21	NA	<20	<84	<23	NA
NA	<150	<22	NA	<20	<100	<21	NA	<20	<84	<23	NA
NA	<150	<22	NA	<20	<100	<21	NA	<20	<84	<23	NA
NA	<150	<22	NA	<20	<100	<21	NA	<20	<84	<23	NA
99.99	11000	<5.4	>99.99	6	5100	<5.3	>99.99	<4.9	5500	<5.7	>99.99
98.98	8500	<5.4	>99.99	<5.1	3000	<5.3	>99.99	75	10000	<5.7	>99.99

APPENDIX D
VAPOR TREATMENT TECHNOLOGY COST COMPARISON

SITE FT-002, PLATTSBURGH AIR FORCE BASE, NEW YORK

COST COMPARISON OF FULL-SCALE VAPOR TREATMENT TECHNOLOGIES
FLAMELESS THERMAL OXIDATION DEMONSTRATION
FIRE TRAINING AREA FT-002
PLATTSBURGH AIR FORCE BASE, NEW YORK

Vapor Treatment Technology	Capital Cost ^{a/}	Shipping and Installation Setup	Annual Costs (365 days)			Expected DRE %	Cumulative Annual Costs over Cost Per Pound of VOC Treated ^{a/}			Comments	
			Labor	Analytical	Electricity		Fuel ^{b/}	1 year	2 year		3 year
Thermatrix FTO	\$200,000	\$12,000 ^{d/}	\$8,000 ^{d/}	\$10,800 ^{d/}	\$1,500 ^{d/}	99.99	\$21,900	\$254,200 \$3.41	\$296,400 \$1.99	\$338,600 \$1.52	Thermatrix estimate Does not include SVE blower.
Thermatrix Resin Bed	\$210,000	\$12,000 ^{d/}	\$12,000 ^{d/}	\$10,800 ^{d/}	\$13,140 ^{d/}	95	\$0	\$257,940 \$3.46	\$293,880 \$1.97	\$329,820 \$1.48	Thermatrix estimate Does not include SVE blower.
E Products Thermal Oxidation	\$43,111	\$12,000 ^{d/}	\$8,000 ^{d/}	\$10,800 ^{d/}	\$3,000 ^{d/}	99	\$76,957	\$153,868 \$2.07	\$252,624 \$1.70	\$351,381 \$1.57	E Products estimate Does not include SVE blower.
Therm Tech Thermal Oxidation	\$50,500	\$12,000 ^{d/}	\$12,000 ^{d/}	\$10,800 ^{d/}	\$3,000 ^{d/}	95	\$59,367	\$147,667 \$1.98	\$232,833 \$1.56	\$318,000 \$1.42	ThermTech estimate Does not include SVE blower.
Therm Tech Catalytic Oxidation	\$75,800	\$12,000 ^{d/}	\$12,000 ^{d/}	\$10,800 ^{d/}	\$3,000 ^{d/}	90	\$49,472	\$163,072 \$2.19	\$238,344 \$1.60	\$313,616 \$1.40	ThermTech estimate Does not include SVE blower.
Carbon	\$50,000	\$12,000 ^{d/}	\$12,000 ^{d/}	\$10,800 ^{d/}	\$1,500 ^{d/}	^{d/}		\$1,327,300 \$17.83	\$2,592,600 \$17.41	\$3,857,900 \$17.27	Parsons ES est. assuming 240 lb/day mass VOC load, 15 % carbon load rate per day, \$2.50/lb carbon regeneration, 2 x 20K lb vessels

Notes:

a/ The cost per pound of THC treated equals the cumulative costs divided by the cumulative number of days of operation, assuming mass recovery of THC at 204 lb/day, and vapor flow rate of 500 cfm.

b/ Actual propane fuel costs at Plattsburgh AFB were \$1.15/gallon or \$12.55/million BTU assuming 91,600 BTU, per gallon.

c/ Vendor derived cost.

d/ Estimated costs. Labor costs were approximated and include time associated with general operation and maintenance of the system and collection of vapor samples. Analytical costs were approximated at \$300 per sample, assuming that during startup three influent and effluent samples are collected, a regular sampling schedule of once a month, and three quality control samples (total number of samples = 6 + 24 + 6 = 36).

BUILDING 181, AIR FORCE PLANT 4, TEXAS

TABLE 4.1
COST COMPARISON OF FULL-SCALE VAPOR TREATMENT TECHNOLOGIES
FLAMELESS THERMAL OXIDATION DEMONSTRATION
BUILDING 181
AIR FORCE PLANT 4, TEXAS

SVE Treatment Alternative	Vapor Treatment Vendor	Influent Flow Rate (scfm)	Capital Cost	Total Annual Operation and Maintenance Cost	5-Year Present Worth Cost	5-Year Present Worth Cost per Pound of TCE Treated	12-Year Present Worth Cost	12-Year Present Worth Cost per Pound of TCE Treated
Catalytic Oxidation	Catalytic	850 ^{a/}	\$155,940	\$28,020	\$280,679	\$1.01	\$418,911	\$0.63
	Combustion	1140 ^{b/}	\$173,730	\$38,490	\$345,080	\$0.93	\$534,962	\$0.60
	E Products	850	\$168,760	\$63,780	\$452,696	\$1.62	\$767,342	\$1.15
	Catalytic Oxidation	1,140	\$168,760	\$84,260	\$543,869	\$1.47	\$959,549	\$1.08
	Global	850	\$189,800	\$20,850	\$282,620	\$1.01	\$385,479	\$0.58
	Catalytic Oxidation	1,140	\$249,700	\$26,540	\$367,851	\$0.99	\$498,781	\$0.56
	EnviroReps	850	\$196,000	\$63,780	\$479,936	\$1.72	\$794,582	\$1.19
	Catalytic Oxidation	1,140	\$247,000	\$84,260	\$622,109	\$1.68	\$1,037,789	\$1.17
Thermal Oxidation	Thermatrix	850	\$458,400	\$32,370	\$602,511	\$2.16	\$762,196	\$1.14
	Flamless Oxidizer	1,140	\$458,400	\$43,330	\$651,292	\$1.76	\$865,056	\$0.97
	Thermatrix	850	\$373,400	\$32,370	\$517,511	\$1.85	\$677,196	\$1.01
	Flamless Oxidizer ^{c/}	1,140	\$403,400	\$43,330	\$596,305	\$1.60	\$810,056	\$0.91
	E Products	850	\$143,760	\$87,470	\$533,159	\$1.91	\$964,675	\$1.44
	Thermal Oxidizer	1,140	\$143,760	\$116,030	\$660,302	\$1.78	\$1,232,713	\$1.39
	EnviroReps	850	\$190,000	\$87,450	\$579,310	\$2.07	\$1,010,727	\$1.51
	Thermal Oxidizer	1,140	\$207,000	\$116,030	\$723,542	\$1.95	\$1,295,953	\$1.46
Innovative with Carbon Treatment	Carbon Resources	850	\$85,140	\$81,100	\$446,181	\$1.60	\$846,272	\$1.26
	Thermatrix	1,140	\$101,140	\$107,020	\$577,572	\$1.56	\$1,105,533	\$1.24
	Padre	850	\$206,800	\$95,720	\$632,926	\$2.27	\$1,105,142	\$1.65
	PTI	1,140	\$297,800	\$47,670	\$510,017	\$1.38	\$745,188	\$0.84
	MIAB	850	\$206,770	\$102,860	\$664,682	\$2.38	\$1,172,121	\$1.75
	Concentrator	1,140	\$219,970	\$132,770	\$811,035	\$2.19	\$1,466,030	\$1.65
	PTI	850	\$331,770	\$80,330	\$689,383	\$2.47	\$1,085,675	\$1.62
	MIAB Photocatalytic	1,140	\$344,970	\$99,740	\$788,993	\$2.13	\$1,281,040	\$1.44

Source: Based on data presented by Jacobs (1997); capital and operation/maintenance costs rounded to nearest \$10.

^{a/} The cost per pound of TCE treated equals the cumulative costs divided by the cumulative number of days of operation, assuming a mass recovery of TCE at 153 lb/day, and vapor flow rate of 850 scfm.

^{b/} The cost per pound of TCE treated equals the cumulative costs divided by the cumulative number of days of operation, assuming a mass recovery of TCE at 203 lb/day, and vapor flow rate of 1,140 scfm.

^{c/} Source: Based on quote received by Parsons ES from Thermatrix, Inc. (Rick Scheig), in December 1997.

**SOURCE AREA REDUCTION SYSTEM,
FORMER LOWRY AIR FORCE BASE, COLORADO**

**CAPITAL AND OPERATING COST COMPARISON
OF FTO AND GRANULAR ACTIVATED CARBON FOR TREATMENT OF SOIL VAPORS
FTO TREATMENT SYSTEM DEMONSTRATION
SOURCE AREA REDUCTION SYSTEM
FORMER LOWRY AFB, COLORADO**

Inter-agency WBS # ^{c/}	Cost Element	DEWATERING PHASE (80 cfm) ^{a/}		TREATMENT PHASE (250 cfm) ^{a/}	
		Thermatrix Inc. FTO Unit ES-100 Model (1 unit) (100 scfm)	CARBOTROL Corporation G-4 Adsorbers (2 units in series) (1,000 pound per unit)	Thermatrix Inc. FTO Unit GS-100 Model (1 unit) (500 scfm)	CARBOTROL Corporation G-4 Adsorbers (2 units in series) (1,000 pound per unit)
		<u>Cost</u>	<u>Cost</u>	<u>Cost</u>	<u>Cost</u>
33-14	<u>Capital Cost (vapor treatment only)</u>				
	Treatment Unit	\$103,115 ^{u/}	\$8,008	\$300,000 ^{e/}	\$8,008
33-01	Design/Labor/Installation ^{u/}	\$11,700	\$5,200	\$11,700	\$5,200
	Total Capital	\$114,815	\$13,208	\$311,700	\$13,208
	<u>Operating Cost (daily)</u>				
	Includes:				
33-14-XX-01-08	• Maintenance/Monitoring (includes monthly O&M) ^{g/}	\$131	\$65	\$131	\$65
33-14-XX-01-08	• Analytical (includes analysis costs and labor) ^{g/}	\$89	\$89	\$89	\$89
33-14-XX-01-08	• Supplemental Fuel	none	none	\$57	none
33-14-XX-01-08	• Carbon Costs ^{h/}	none	\$12	none	\$32
33-14-XX-01-08	• Utility Requirement ^{u/}	\$90 (electricity)	none	\$5 (electricity)	none
	Total Cost (3 Year Duration) ^{y/}	\$454,265	\$194,978	\$620,490	\$216,878

**CAPITAL AND OPERATING COST COMPARISON
OF FTO AND GRANULAR ACTIVATED CARBON FOR TREATMENT OF SOIL VAPORS
FTO TREATMENT SYSTEM DEMONSTRATION
SOURCE AREA REDUCTION SYSTEM
FORMER LOWRY AFB, COLORADO**

- a/ Vapor flow-rate (80 cubic feet per minute [cfm]) expected during dewatering phase (Shingledecker, 1998).
- b/ Maximum vapor flow-rate (250 cfm) expected during treatment phase (Shingledecker, 1998).
- c/ USEPA, 1995.
- d/ Cost based on vendor quote from Thermatrix Inc. Costs include \$95,000 for each ES-100 unit plus an additional \$3,615 for a fume blower and knockout drum (Parsons ES, 1998) and \$4,500 for control valves (Parsons ES, 1998), both of which are necessary for smooth operation of the FTO unit.
- e/ Cost based on vendor quote from Thermatrix Inc. Costs include \$95,000 for each ES-100 unit (\$190,000 total) plus an additional \$3,615 for a fume blower and knockout drum (Parsons ES, 1997) and \$4,500 for control valves (Parsons ES, 1997), both of which are necessary for smooth operation of the FTO unit.
- f/ Design/Labor/Installation costs were estimated at 180 hours at \$65/hour for the FTO systems and 80 hours at \$65/hour for the carbon adsorption systems.
- g/ Based on actual Parsons ES cost for the FTO unit. The maintenance costs for the carbon adsorption system were reduced by 50 percent due to the non-mechanical nature of the CAC system.
- h/ Based on carbon usage rates supplied by CARBTROL Corporation (see Appendix D). Carbon usage rates assume a temperature of 75°F and a relative humidity of the influent vapor stream of 50%. Increases in temperature and relative humidity of the vapor stream will decrease the carbon usage efficiency increasing carbon costs. Cost for carbon usage assumed to be \$1.15/pound, which includes the cost of the replacement carbon, reactivation, transportation, and labor.
- i/ Based on electricity requirements supplied by Thermatrix. Cost was estimated at \$0.08/kW-hour.
- j/ Total treatment duration estimated by Versar (1996) assumes the system would operate for 3 years at a flow rate of 80 cfm or 250 cfm.